Early Iron Age Greek copper-based technology: votive offerings from Thessaly

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Declaration

I, Stavriani Orfanou, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

The thesis aims to explore metallurgical technology in Greece during the Early Iron Age (EIA). Emphasis is put on copper-based metallurgy as there is a large body of evidence in the archaeological record to support the large-scale production of copper-tin-lead alloy objects in the post-Mycenaean period and the first half of the 1st millennium BC. Such artefacts played a significant role having both utilitarian and symbolic features as they have been deposited by the thousands as votive dedications to the EIA sanctuaries such as Delphi and Olympia. Questions in regard to these objects' mode of production, circulation, use and the circumstances of their ritual deposition, as well as of the sanctuaries' economics and their ability to attract a significant proportion of available wealth thus arise.

The assemblage of copper-based artefacts recovered at the sanctuary of Enodia in Thessaly has been selected in order to investigate EIA copper metallurgy during this period of transformation for Greek society. A sample of almost three hundred objects has been selected and investigated with the application of archaeometric quantitative and qualitative analytical methods. Meanwhile, research focused on the objects' chemical compositions, metalworking techniques, use, and typological classification which have been brought together for an integrated interpretation of copper-based production. Specific focus has been put on the organisation and mode of production, the technological choices related to practices of alloying and metalworking of copper, as well as the dialectic relationship between the objects' form and intended use with their chemical and mechanical properties. Finally, results from Thessaly are brought together with published data from additional cultic and secular sites in mainland Greece in order to discuss inter-regional technological variation and affinity. Overall, the study addresses issues of the copper-based metallurgy's integration into EIA Greek society.

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Introduction

> *'[...] this is a [study] about technology; it is, therefore, first and foremost a [study] about people'*
>
> (Dobres 2000, p. 1)

Copper-based metallurgy has been an integral element of past societies throughout antiquity in the majority of cultures and regions around the world. During the first half of the 1st millennium BC in the eastern Mediterranean copper-based artefacts have been produced and consumed in abundance fulfilling both utilitarian purposes and serving as vessels of symbolic concepts and non-verbal communication including the transfer of ideas by means of style, fashion and the performance of sacrifices. In Early Iron Age Greece and the Aegean, copper-based objects have been widely used to cover peoples' everyday needs and as sacred offerings to the dead and the gods, as the result of the continuation of a long standing tradition tracing back already in the Bronze Age. This depositional activity reached its maturity in the Geometric and Archaic periods in the 8th and 7th centuries BC when metal offerings have been dedicated by the thousands in the sanctuaries of Greece, Asia Minor and Magna Graecia.

The above pattern of the metal objects' ritual removal from circulation has been largely responsible for the preservation of substantial numbers of copper-based artefacts of votive character in the archaeological record of Greece (see also Chapters 1 & 2). Consequently, a significant body of evidence points to the copper technology as well-embedded in Early Iron Age Greek communities and certain questions arise in regard to the metallurgical practice and its integration into early Greek society. The present study focused on the metallurgical technology of copper and its alloys in order to promote the understanding of post-Mycenaean and early 1st millennium BC peoples of mainland Greece. The main aims of the study included a detailed investigation of respective communities' technological organisation and know-how as portrayed through the manifold cultural expressions that took place during the different stages of the metallurgical practice and which, finally, left their imprint on the finished objects. Finally, investigation of the ritual and symbolic consumption of copper-based artefacts in Early Iron Age Greece aimed to promote the understanding of the groups and individuals involved in the manufacturing and dedication of metal artefacts, as well as in sanctuary administration.

The archaeometallurgy of copper: a concise overview

Archaeometallurgical investigation of copper relates to all stages of its production cycle and the finished objects' biographies including primary and secondary production of copper metal and alloys, as well as patterns of the artefacts' use, re-use, recycling and final disposal (e.g. Costin and Hagstrum 1995, Costin 2005). Detailed examination of a) the mode of the metallurgical production as illustrated in the provision, handling, and primary and secondary processing of the raw materials, b) the degree of standardisation in the various stages of technological practice, and c) technological traditions and the incorporation of innovations can provide new insights into past societies' organisation (e.g. Sillar and Tite 2000 on technological choices, Ottaway 2001, Martinón-Torres 2002 for an overview of the chaîne opératoire approach).

From the second half of the twentieth century and the 1980s onwards, in particular, the ways in which exploration of the aforementioned aspects may contribute to an enhanced understanding of past societies have been and, to an extent, still are discussed and developed by archaeologists, archaeometallurgists and anthropologists (e.g. Gell 1998, Dobres 2000, Dobres and Robb 2000, Ingold 2001, Schiffer 2001, Miller 2005, Knappett 2012). For instance, the exploration of the limits and potentials of agency and materiality as theoretical interpretative tools in the study of past material culture and its associated communities continues to be the subject of negotiation as scholars are actively working on these topics (e.g. DeMarrais *et al.* 2005, Hodder 2011, 2012a). Finally, the role and contribution of scientific analysis in the interpretation of past societies, its integration into the theoretical and anthropological concerns and the direction that this research approach should follow have also been the focus of extended discussions and debates (e.g. Killick 2002, 2015, Jones 2004, and comments by Boivin, Bray and Pollard, Gosden, Killick, Mithen, Needham, Taylor, Thomas, Pollard and Bray 2005, Martinón-Torres and Killick 2015).

Research background

Metal artefacts of early Greece

Despite the vast numbers of copper-based objects recovered from Early Iron Age cult sites all over the Greek mainland and the islands, they have not yet been the subject of a targeted, consistent, systematic or interdisciplinary archaeometallurgical approach. Meanwhile, such a research focus could facilitate the broader understanding of the copper-based technology during this period of transformations which led to the emergence of the city-states in the Archaic period. When it comes to these votive dedications, archaeological exploration has focussed more on their symbolic aspects and forms, e.g. their typology, rather than on their technology and the circumstances of their production. This is, for example, characteristically reflected in two symposia held in the 1980s, namely '*Gifts to the Gods'* in Uppsala (Linders and Nordquist 1987)' and *'Early Greek Cult Practice'* in Stockholm (Hägg *et al.* 1988), which have to an extent set the ground for a discussion of various aspects of the dedication practice but with rather limited references to its technology. This notable gap was to an extent addressed by a third symposium on the *'Economics of Cult in the Ancient Greek World'* which followed just a few years later (Linders and Alroth 1992) where a couple of papers dealt with the relationship between early Greek sanctuaries and metallurgical workshops (Hägg 1992, Risberg 1992, see also 1997). Furthermore, a paper in the early 2000s has also addressed the topic with some references to Early Iron Age sites (Psaroudakis 2003). Nonetheless and despite the above contributions, emphasis of scholarship has been traditionally away from the quantitative analyses of Early Iron Age bronzes. Publications of a small number of scholars form the exception to the above rule as only a handful of studies mostly from the 1970s and 1980s have dealt with the scientific quantitative analyses of Early Iron Age copper-based artefacts emphasising the neglect of the topic in recent years. The majority of these works were conducted and published as parts of excavation reports and they did not necessarily approach Early Iron Age copper-based metallurgy holistically by incorporating elements of the overall cultural context as emphasis was rather put on the analytical results *per se* (for a detailed discussion see Chapter 2.5).

Looking at the aforementioned list of publications focus certain research strands are identified. Hence, one can distinguish studies that have dealt with the typology of the artefacts. Those studies' emphasis has been primarily put on the establishment of diachronic sequences of the various artefact types such as, for example, the fibulae or the Macedonian bronzes, and the identification of imitations. Typological studies have traditionally been used, as also partly done in this study too, as the main methodological tool for the dating and provenancing of the inorganic finished objects. This is achieved through the different types' attribution to specific cultural contexts, as well as investigation of their geographic spread (e.g. Blinkenberg 1926, Kilian 1975, Voyatzis 1990, Bouzek 1997). Another distinct research strand has focused on the particular relationship between sanctuaries and metallurgy through the investigation of *in situ* production remnants and by-products such as slag or tuyère fragments such as the work of Hägg and Risberg, and Psaroudakis' synthesis of presently available evidence evidence (see also Chapter 1.2.1). Meanwhile such a direction has often explored the context of Late Bronze Age Cyprus (Knapp 1986, Kassianidou 2005). An third direction of archaeological enquiry can be distinguished in the excavation reports or other published analytical data sets whose primary aim has been, on the one hand, to present the quantitative characteristics, physical properties, and compositional groupings of the respective assemblages (e.g. Jones 1980, Riederer 2007), and, on the other, to spot diachronic trends and developments in the metallurgical practices of subsequent periods such as the variations in the arsenic, tin or lead contents in the various copper alloys (e.g. Craddock 1976, 1977, 1978, Rapp *et al.* 1978). Finally, a number of studies has focused on the chemical compositions of the post-Mycenaean and Early Iron Age tin bronzes in Greece and the Aegean in order to address issues regarding the tin supply and, by extension, their international connections via networks of metals' trade and exchange. The latter have also contributed to the debate surrounding the 'tin shortage' hypothesis posed by Snodgrass in the early 1970s.

Notable exceptions to the above are the publications by Rolley et al. (1983) and Mangou et al. (1986, 1991) which explored the characteristics of Geometric tripod production in light of the eastern influences and cultural hybridity (see also Chapter 2.4). Overall, past scholarship's objectives have followed rather distinct directions, while not holistically accounting for the various socio-economic aspects of copper-based metallurgy and its incorporation into early Greek society. Nevertheless, recent archaeometallurgical studies have moved beyond a rather descriptive stage to a synthetic one in order to illustrate social processes and cultural changes of early Greece. This is characteristically seen in the work of Kostoglou (2008, 2010, 2011) which even though it deals with iron technology and not copper, it investigates metal technology in conjunction with the internal organisation of Iron Age society and the construction of contemporary Greek communities' identities by focusing on the 'interaction between ancient technology and society' (Kostoglou 2013, p. 313). Finally, Kostoglou has moved beyond the aforementioned establishing of typologies and the limitations these involve towards a more informative exploration of ancient metal artefacts that promotes the understanding of ancient societies by analysing the full life-cycles and object biographies of ancient metal artefacts (Bruno and Kostoglou 2012).

Taking into consideration the above scholarly tradition, the assemblage of copper alloy votive offerings dedicated to the sanctuary of Pherae in the Thessalian plain has been selected for quantitative and qualitative analyses in order to investigate aspects of Early Iron Age Greek society and the organisation of technology as reflected in the copper metallurgy. The assemblage has a strong local character, while certain groups of objects such as the Macedonian bronzes point to contacts with northern Greece and the Balkans, while other imports suggest connections with the eastern Mediterranean and Anatolia (Kilian 1975, Bouzek 1985, 1988, 1997) (see below this chapter for a discussion of the research aims).

Ancient Pherae and Thessaly

Scholarly interest for the site of ancient Pherae was expressed already from the late 19th and early 20th centuries, while more systematic exploration took place from the 1970s onwards. Early explorations of Thessaly and Pherae were conducted mostly by historiographers and travellers. These early contributions to the history of Pherae include Hansen's (1933) work on the *'Early Civilization in Thessaly'*, and Westlake's (1935) *'Thessaly in the 4th century'* where despite the apparent emphasis on the Hellenistic period, Westlake attempted a diachronic study of Pherae from as early as prehistoric times. The contribution of these works lies to an extent in the synthesis of a significant body of information from ancient literary sources including Herodotus, Thucydides, Strabo, Aristotle, Dionysius of Halicarnassus, Isocrates, and Aristophanes, as well as the detailed descriptions of the plain's surroundings prior to the effect of modern interventions. Overall, the 4th century and the Hellenistic period of Thessaly has attracted much attention, as also seen in the recent work of Graninger (2011) on Thessalian koinon, due to the important role of the Pheraean tyrants Alexander, Jason and their descendants in establishing Pherae as a major military power which was influencing and engaging with communities throughout Greece (Morgan 2003, p. 23). Useful information regarding the socio-political organization and landscape of ancient Thessaly is also to be found in the travels of Leake (1835), *'Travels in Northern Greece'*, and Stahlin (2002, first published in 1924), *'Das Hellenische Thessalien'*. Although both works do not concentrate solely on Pherae and, in the latter, Pherae is only briefly mentioned, they do provide a useful insight on the local climate and environment, as well as the history and daily tasks of past and contemporary habitants of Thessaly.

Early archaeological investigations of ancient Pherae and its environs include the joint excavation by Arvanitopoulos and Béquignon on behalf of the Greek Archaeological Service and the French School respectively in 1925-1926. Results of this expedition were published in a volume by the University of Strasbourg, *'Recherches Archaéologique a Phères de Thessalie'*, in which emphasis was put on not only the settlement and its architectural remains, but also the area of the Enodia sanctuary and temple, whereas the inscriptions and portable finds, such as the terracottas, metal artefacts and pottery were only briefly discussed (Béquignon 1937). In the volume, no catalogue of finds has been included with the exception of a few selected objects nor, in fact, any extended interpretation. Its scope was to present rather than interpret the findings of the excavation season. Nonetheless, the unearthing of the temple itself and the preceeding Protogeometric necropolis alone were significant advances in the understanding of ancient Pherae. Following this work, excavations at the sanctuary were resumed in 2006-2007 by Dougleri-Intzesiloglou and Arachoviti from the 13th Ephorate of Prehistoric and Classical Antiquities in Volos (Ministry of Culture), which aimed to explore aspects that the former excavators had neglected, such as the pottery assemblage and the stratigraphy of the site which would allow to establish relative chronologies (Arachoviti pers. com.). Examination of the latter excavation season's findings is still ongoing and publication of preliminary results is pending.

As discussed above, archaeological research at Pherae presents a gap between the early excavation seasons in the 1920s and the 1970s. A renewed interest in the archaeology of Thessaly and Pherae was expressed in the 1980s and 1990s when a series of international conferences took off. A conference on ancient Thessaly, *'La Thessalie: Quinze Années de Recherches Archéologiques, 1975-1990. Bilans et Perspectives* , held in Lyon brought in the spotlight fifteen years of research in the region and dealt with various aspects of Thessaly including ancient Pherae (Helly 1994), while the *'Hypereia: Pherae-Velestino-Rigas''* conferences held every four years from 1986 onwards at the actual site of Pherae (modern Velestino), focus solely on the site's archaeological and ethnographic explorations (Kamilakis and Polymerou-Kamilaki 1990, Karamberopoulos and Kakavogiannis 1994, Karamberopoulos 2002, 2006). The *Hypereia* meetings approach the archaeology of Pherae diachronically from prehistory, through to the Byzantine period, and up to its modern history. Finally, the 'Archaeological work of Thessaly and central Greece' held regularly every three years since 2003 have also promoted the research of ancient Thessaly and Pherae.

At the current stage of research we have an overall good understanding of Pherae's history and prehistory, from the Neolithic to Late Byzantine times, and of its Iron Age community in particular as a number of systematic and rescue excavations and surveys have brought to light many parts of the settlement and its city plan, as well as its surroundings and periphery (Arvanitopoulos 1926, Chrysostomou 1983, Arachoviti 1994, Doulgeri-Intzesiloglou 1994, 2000, Doulgeri-Intzesiloglou and Arachoviti 2006, Arachoviti *et al.* 2012). Archaeological research has revealed aspects of Pherae's relations to the rest of the Thessalian communities and its important role throughout the Iron Age, but also in the broader Greek and eastern Mediterranean context, and the changes that the settlement underwent from the Geometric down to Roman times. Nonetheless, there are still several aspects that need to be more thoroughly investigated that will lead to a better understanding of the site's subsequent periods of habitation and the diachronic social, economic, political and ideological changes of its long life history. In the present study, research will employ information generated during the analyses of the copper-based artefacts recovered at the Enodia sanctuary to address issues of the metallurgical technology and to discuss the social groups and individuals involved in the different stages of production, use and votive deposition of these metal artefacts during the Protogeometric, Geometric and Archaic periods including the metalworkers and devotees.

Research aims

Given the current state of research of early 1st millennium BC Greek metallurgy as outlined above, an interdisciplinary approach is needed for an integrated exploration of the massive production and circulation of copper-based artefacts. Here a methodological model is employed as a means to enhance the current understanding of early Greek society by looking at the products of its copper technology. This framework for the study of metal artefacts largely draws from previous work already conducted in the broader context of material culture and archaeological science in a range of periods and archaeological contexts during the last decades such as in the cultures of Mesoamerica (e.g. Uribe Villegas and Martinón-Torres 2012, DeMarrais 2013). However, a similar approach has not yet been adopted for the investigation of the Early Iron Age Greek copper-based production as scholars have so far paid little attention towards a contextualised exploration of the copper-based assemblages. Thus, methodological and theoretical tools already established and negotiated to various degrees in the study of material culture and past technologies particularly from the 1980s are employed in the present study in order to discuss the social context of copper-based metallurgical technology and its products.

The present study draws upon theoretical frameworks from the disciplines of archaeology and anthropology and moves beyond approaches that have dealt with technologies as merely 'chronological or cultural markers' (Ucko 1989, p. x) as partly seen in the aforementioned research record (see also above Research Background - Metal Artefacts and Chapter 2.5). An extended discussion of the various approaches to material culture and past technologies is beyond the scope of this introduction as substantial scholarship has so far dealt with the anthropology of technology (van der Leeuw and Torrence 1989, Lemonnier 1993, Schiffer 2001, Costin 2005, Hruby and Flad 2007) and human-thing interaction (Tilley *et al.* 2006, Hodder 2012b, Lemonnier 2012, Watts 2013). The study also owes to the interpretative tools of technological choices, chaîne opératoire and object biographies (e.g. Lemonnier 1993, Gosden and Marshall 1999, Sillar and Tite 2000), as well as the concepts of materiality and agency (e.g. Appadurai 1986a, Gell 1998, Dobres 2000, Jones 2004, Miller 2005), and the role of material culture in the shaping of social memory (e.g. Hendon 2000, Jones 2007, Meirion Jones and Bradley 2012). Overall, the above approaches underpin the relationship between material and human agents.

Metallurgical technology and the artefacts themselves are hereby seen as a construction of contemporary society, while society itself as equally shaped by its material culture and existing technological knowledge. Quantitative and qualitative investigation (see Chapter 3) of the Pheraean copper-based assemblage explored a) the organisation and standardisation of production, b) the materiality and symbolism of the metal votive offerings, and c) the interaction between material and immaterial aspects of copper technology, namely the raw materials, techniques and technological choices practiced. Newly generated results were also incorporated in a discussion which largely drew from studies of past technologies which highlight the active role of material culture in the formulation and development of past societies and the dialectic interaction between agents, the physical environment and respective ideologies through which social balances were ensured. Moreover, the present study investigated the degree of labour and effort invested during the metallurgical processes. Both the individual and collective input were explored including the impact of individual metalworkers' gestures, e.g. traces of hammering and annealing, and the established technological traditions and habits such as patterns in the use of specific alloy recipes. In addition, the study dealt with the economics of the Enodia cult which was proudly managed by the Pheraean society and the ideological choices of certain groups within the latter, since religious belief and its material expression are both aspects of the same coin (Morgan 1996, p. 44). Finally, religious and ideological manifestations of individual and collective identity of the local communities of Pherae and Thessaly, and possibly of visitors from elsewhere, at this cult site have been considered. Addressing the above was possible by a detailed examination of the technological choices materialised in the Pheraean assemblage in conjunction with the current understanding of the contemporary socio-economic and religious context.

Technological choice is above all a cultural, social, economic, political (Dobres 2000), and circumstantially religious choice. Metal votive offerings, due to their durability, are strong manifestations of communication with transcendent powers, but also a memento; a form of exchange that is socially and economically significant (Mauss 2002). Examination of the physical properties of these offerings and reconstructing their object biographies promoted the understanding of the shift in their value from 'their primary purpose to one worthy of ritual deposition' (Erdman 2012, p. 89). Finally, investigation of the Early Iron Age metallurgical technology with the bronze votive offerings as a starting point allowed the exploration of the organization and economy of Early Iron Age Thessalian society (Risberg 1992, p. 33). It also provided an insight into the major cult practices that formed a common denominator and a unifying factor for the communities of mainland Greece and the Aegean over nearly a millennium of major cultural, political and technological changes.

A sample of some three hundred copper-based artefacts have been examined both invasively (cut samples) and non-destructively (surface analysis). Compositional results were brought together with observations of the macroscopic features including their typology, size and decoration in order to explore aspects of contemporary metallurgy and its integration into society. Examination of the finished objects addressed questions on the nature of the raw materials, metals and alloys used, and the metalworking techniques employed in the production of the metal artefacts. The analytical results were also synthesised with the objects' function (utilitarian, symbolic) and artefact types as defined by their form, use and typology, i.e. the set of decorative elements borne by each artefact that may result from its association with a specific culture and/or geographical region over a given chronological span. Meanwhile, the synthesis of analytical and typological data enabled a detailed discussion of the various operating regional workshops. Furthermore, investigation of the votive offerings from Pherae focused on the relationship of the artefacts' technical and chemical properties with the potential of their dedication, and how the latter may have impacted on the metallurgists' decision making during their manufacturing; namely the impact, if any, of their dedication on the *'wider world of things'* including their production technology (Osborne 2004). Finally, people's attitudes and responses to availability of resources and knowledge in regard to the production of these '*divine'* gifts have been considered too.

More specifically, this study aimed to explore the following aspects of the copper-based Early Iron Age Greek metallurgy:

- the organisation of production:
  - the procurement of raw materials, alloying, and standardisation of the metallurgical practice
  - technological responses to the availability of natural resources and cultural factors
  - the technological choices that took place in conjunction with the function, use (symbolic or utilitarian), artefact type or additional macroscopic characteristics (e.g. size) of the copper-based objects
  - evidence of mixing and recycling of metals as reflected in the major and minor/trace elements
- the economics of the Enodia sanctuary:
  - its role in local copper-based production
  - the presence and, if so, the nature of imported offerings
- the social role of copper metallurgy in early Greece:
  - the active role of these copper-based votive offerings amongst contemporary Greek communities
  - the possibility for a value system based on tin bronze
  - construction of collective memory through the processes of public exhibition, hoarding and safe-keeping by the religious institutions, as well as their contribution in the sustenance of social balances by the semi-formal, semi-voluntary obligation of the ruling classes to

contribute a proportion of their material wealth to the sanctuaries, almost as a pre-city-state taxation practice.

Thesis outline

The thesis is divided in three parts each focusing on the archaeological context and background of early Greek society, cultic activity and the available research record of copper-based technology (Chapters 1 & 2), on the material, methodology, and results of the analytical investigation (Chapters 3 to 7), and lastly on the synthesis of new and existing data and an integrated discussion of the Early Iron Age copper-based production in Thessaly and the broader Greek region (Chapters 8 to 10).

The first chapter deals with the archaeology of post-Mycenaean and Early Iron Age Greek society and the archaeology of Thessaly and ancient Pherae between the 11^{th} and 7^{th} centuries. It also includes a discussion of the production and consumption of copper-based objects and the emergence and integration of the sanctuaries into contemporary society and their relationship with the metallurgical technology and the metal votive offerings. In addition, past and current debates on the interpretation of the available archaeological record and the consequences that these had on the understanding of early Greece are also concisely discussed. In the second chapter, the available analytical data and the archaeological questions posed by respective scholars are discussed in detail, as well as any limitations of the analytical methodologies, instruments employed and any underlying hypotheses that these studies were built on. In turn, the need for an integrated archaeometallurgical research approach for the discussion of Early Iron Age copper metallurgy in Greece is highlighted.

In the third chapter, the selected sample from Pherae is presented in terms of typology, context and dating. The chapter continues with the discussion of the sampling strategy, analytical techniques and the methodological issues that arose during the study. The two quantitative techniques employed, namely EPMA and pXRF, and issues of instrument comparability are presented in detail in order to explore the impact of methodologies on the archaeological record's interpretation.

In the following four chapters the generated analytical results produced during examination of the sample are presented in much detail. In the fourth chapter the bulk composition of the objects and the alloying elements, namely tin and lead, are discussed, while the fifth chapter deals with the minor and trace elements. In the sixth chapter, the possibility for different alloying recipes linking to different metalworking workshops is further explored. Finally, in the seventh chapter qualitative results are brought together with the objects' chemical compositions and typology to discuss the metalworking techniques employed in Early Iron Age Thessaly.

In the eighth chapter, the published data of copper-based artefacts from Early Iron Age Greece (as already discussed in the second chapter) are brought together with the newly generated results from Pherae. This comparative approach allowed the discussion of Early Iron Age copper-based metallurgy in the broader context of the Greece, while it also highlighted the discrepancies of technologies with a rather local character. Furthermore, datasets from sanctuaries have been compared and contrasted to those from secular contexts, while artefact typology was also considered.

In the ninth chapter, an integrated discussion brought together the results and focussed on aspects of organisation of production and technological choices with reference to the objects' bulk chemical composition, trace element fingerprints, typology, and chronology. In addition, the objects' symbolic connotations as illustrated through the practice of their ritual deposition and the implications for society's attitudes towards these objects' value and the process of their sanctification was discussed. Lastly, concluding remarks and suggestions for future research directions are included in the tenth and final chapter.

Part I

Chapter 1. Early Iron Age Greece and the sanctuaries

1.1 Early Iron Age Greece and Thessaly

The Greek communities in the period following 1200 BC and into the first centuries of the 1st millennium BC underwent a series of transformations which drifted away from the socio-economic Mycenaean palace organisation. These changes gradually formed the basis for new expressions of urbanisation which reached their maturity in the Archaic and Classical periods. These changes were expressed in the formation of a network of city-states and *'big sites'* (for the latter term see Morgan 2003), as well as the erection of monumental architecture and formalisation of religion. New burial customs such as the predominance of single burials also took place, while new networks of mobility and colonisation developed. All the above manifestations were the result of contemporary cultural changes, as much as they contributed in processes of identity renegotiation for the peoples of mainland Greece and the islands.

This transformation of early Greek society at the break of the 1st millennium BC characterised by cultural variation in comparison to the Mycenaean tradition has attracted much scholarly attention and has initiated a longstanding debate as to which circumstances accounted for the collapse of the Mycenaean palaces and the apparent stagnation (?) that followed in much, though not all (see discussion below), of mainland Greece and the Aegean. Hence, much discussed topics have involved questions of cultural continuity versus change, theories of poverty followed by revival versus more comprehensive explanations of the respective cultural changes (see below 1.2.1), the character of contemporary settlements and the level of social complexity involved, as well as the existence and the nature of an eastern Mediterranean communication network.

1.1.1 A note on archaeologies of darkness, doom and comebacks

Much of the early research stages around this period of change in the 12th to 10th centuries BC from the 1970s onwards followed a methodology which more evaluated, quantified, and classified rather than aimed to explain and understand the situation and the complex transformations that Greek society underwent. This is markedly seen in authors' word choices which include phrases such as 'the Dark Age', 'the Greek Middle Ages', 'the gap', or 'the void' which were used to describe this period. Moreover, phrases such as the 'Greek Renaissance' and 'revival' were typically used to signify the period from the 8th century BC onwards. Such terms have been, for example, used in the works of

Snodgrass and Desborough '*The Dark Age of Greece'* (2000, first edition in 1971) and '*The Greek Dark Ages'* (1972) respectively. These early volumes have proved quite influential for a series of publications in the 1980s and 1990s which reproduced similar ideas of cultural stagnation, doom, and darkness followed by the revival and rejuvenation of early Greece. This is, for example, seen in Hägg's (1983) '*The Greek Renaissance of the eighth century BC: tradition and innovation'* or Whitley's *'Style and Society in Dark Age Greece'* (1991a). Meanwhile, traces of the above tradition are still seen in works whose main objective was to address the implications of this cultural transition. Thus, even though Coldstream's *Geometric Greece* (2003, first edition in 1977) is entitled after the pottery style which gave its name to the period on the whole, he yet refers to the 8th century as a period of 'new beginnings' for Greek society when it 'emerged from its isolation', while the post-Mycenaean years were described as an 'intervening period that was [later] largely forgotten'; almost as an unwanted relative (Coldstream 2003, pp. 17–18). Meanwhile, references to 'the passing of the dark ages' and 'the Greek renaissance' are still to be found in the titles of the first couple of Coldstream's chapters. Similarly, in Osborne's 1996 volume '*Greece in the Making'* there have been attempts to 'explain the [post-Mycenaean] void' and 'the onset of the Dark Age' which have not been revisited by the author in the more recent second edition (2009, pp. 35–51).

Such ideas of a cultural decline and revival were to an extent driven by 19th century philological scholarship which focused primarily on the study of the Homeric epics and saw the pre-literate state of 12th to 8th century BC Greek society as a 'gap' (Morris 2000, p. 77). This research direction partly reflected contemporary authors' preconceptions on the topic which saw past cultures altogether as an ever growing and adapting living organism which progressed from a juvenile period, e.g. the 11th and 10th centuries BC, to a more mature and complex one in the 8th and 7th centuries BC. Such assigned attributes should be seen as part of the overall theoretical context around the second half of the 20th century when archaeological thought was to an extent driven by Darwinian and cultural evolutionary strands (Shennan 2008). Nonetheless, the aforementioned approaches have been rather rejected as problematic and outdated by more recent scholarship. Notable publications of the early 2000s from Oxford include Morris' *'Archaeology as cultural history'* (2000) in which the author deconstructs the idea of a 'Greek Dark Age' altogether in a chapter entitled 'Inventing a Dark Age', and '*The Protogeometric Aegean'* by Lemos (2002) in which the material culture and recent discoveries from all over mainland Greece, the Aegean and Asia Minor are brought together for an integrated interpretation of Early Iron Age Greek society. Similarly, Mazarakis Ainian (1997) in his volume *'From ruler's dwellings to temples'* discusses the comparative development of Protogeometric and Geometric secular and cult architecture and its impact in the monumental Greek temples' foundation, while he rejects the use of the term 'Dark Age' as a chronological division (Mazarakis Ainian 1997, p.

36). However and despite the above, notions of a 'Greek Dark Age' have been deep-rooted in the archaeology of post-Mycenaean Greece and have been often reproduced by recent scholarship as noted by Dickinson (2006a, p. 4). This is seen not only in the second edition of Osborne's work (2009), but also in Malkin's *'A small Greek world'* (2011) where, for example, he talks about '[…] cities settled in Asia Minor *during the Dark Ages'* (my emphasis) in an attempt to merely refer to the chronological period between 1200 and 750 BC (Malkin 2011, pp. 8, 49). Meanwhile, as argued by Lemos (2002, p. 1) these terms 'have little to offer towards the understanding of either material culture or social, and political structures' of the period in question. What is more, even if these notions of cultural gaps and comebacks as used by Osborne or Malkin have probably lost part of their background in the context of the 1970s and 1980s research, they still limit the potential for an integrated understanding of early Greek society and, thus, they should be avoided altogether no matter how harmless they may seem.

The above is a rather concise discussion of a quite extended topic in the history of archaeology. It is hereby argued that concepts of *change* and *transformation* and similar terms which describe rather than evaluate these chronological periods, i.e. the Protogeometric, Geometric and Early Iron Age altogether, should be used while they have also been adopted in the present study. Below follows an account of the state of post-Mycenaean and Early Iron Age communities in mainland Greece and the Aegean, with particular focus on Thessaly and ancient Pherae which puts into perspective the bronze assemblage from the sanctuary of Enodia.

1.1.2 Everything happens for a reason: Greece in the Post-Mycenaean and Protogeometric periods

The period following the Late Bronze Age was one of substantial transformations for the communities of mainland Greece, the Aegean and Crete. In the aftermath of the Mycenaean palaces, a new social infrastructure started to emerge. The socio-political organization drifted away from the centralised palace economy and well-controlled administration as a pattern of smaller scale self-management for the emerging communities of the 1st millennium BC was gradually established. Evidence that most notably signified these changes in the *status quo* of the Early Iron Age Greek communities has been manifested in the archaeological record in the development of new settlement patterns and burial customs, as well as in the apparent drop in both the settlement and burial numbers from approximately 1200 BC and into the 10th and 9th centuries.

Views of isolation and stagnation of post-Mycenaean communities have been triggered by an emphasis rather put on evidence from the traditional Mycenaean centres, as opposed to settlements in the Mycenaean periphery which have yielded somewhat different patterns of habitation and social organisation (Kyparissi-Apostolika *et al.* 2003). Hence, despite the quantitative drop in the number of post-Mycenaean settlements which is noted for the Greek region overall including Thessaly (Gounaris 2009), there is an increasing number of sites in the archaeological record which have yielded signs of continuous occupation during this transition period. Evidence for continuous activity between the Late Bronze and Early Iron Ages has been, for example, attested in the settlement of Lefkandi and the cult sites at Kalapodi and Eleusis and, in fact, ancient Pherae to mention a few (Popham and Sackett 1980, Doulgeri-Intzesiloglou 1994, Eder 2001a, Lemos 2002, pp. 174–175, Niemeier 2013, Cosmopoulos 2014). Continuity has been also attested in ritual practice such as in the cultic dedication of figurines and ritual drinking (Marakas 2010, pp. 133–135). Meanwhile, continuity of occupation of Mycenaean structures in succeeding periods has been often encountered including the sites of Nichoria in the Peloponnese and Toumba in Thessaloniki (McDonald *et al.* 1983, Mazarakis Ainian 1997, p. 234).

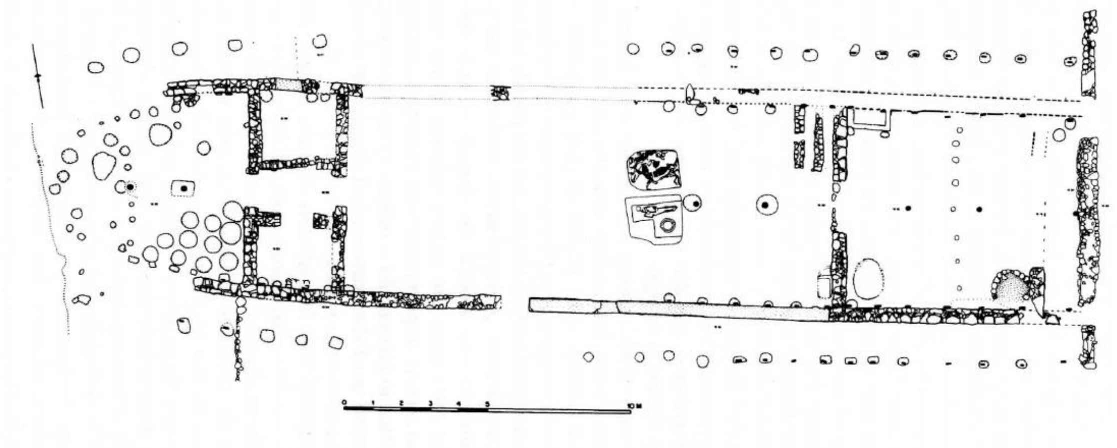


Figure 1.1. Plan of the Protogeometric apsidal building in Lefkandi (after Coulton 1993)

On monumentality

The lack of a long-standing character or any monumental architectural structures of these post-Mycenaean and Protogeometric communities as, for instance, maintained by Osborne (2009, pp. 35–47) has been also debated. However, the argument for the absence of expressions of monumentality has been mostly based on the lack of large ‘cyclopean’ constructions during the Protogeometric and early Geometric periods which have been traditionally considered as the quintessence of Bronze Age tradition. Thus, the above needs revision in light of the available archaeological record. For instance, evidence from Lefkandi and the Protogeometric apsidal building erected at Toumba cemetery during the first half of the 10th century BC leads to a reconsideration of the above portrait of post-Mycenaean communities and the definition of monumentalisation itself. Even though the apsidal construction was not built with massive granite or poros slabs, but instead with more easily attained and readily available material such as mudbricks and wood, it still suggests that the contemporary community had reached such a level of social organisation which allowed the foundation of a large structure with a central social character. The building including the peripheral veranda measures 50 m long and 13.80 wide (Coulton 1993, p. 35) and must be considered as the result of a considerable communal undertaking and collective effort. In addition, the structure underpins an attitude towards large-scale expressions of power and status on the part of the local community of Xeropolis (Figure 1.1). Coldstream, though, has viewed the material wealth recovered at Toumba such as the metalwork and the Near Eastern imports only as a 'temporary awakening' as he has supported a full recovery from isolation only in the 8th century BC (Coldstream 2003, p. 367). Nevertheless, the Lefkandi building should not be viewed as an exception, as similar, though often smaller, apsidal constructions have been recovered in many areas of mainland Greece and the Aegean such as in Toumba Thessalonikis and Poseidi in northern Greece, Nichoria in the Peloponnese, and Koukounaries in the Cyclades (McDonald *et al.* 1975, pp. 80–81, Vokotopoulou 1992, pp. 443–446, Mazarakis Ainian 1997, pp. 43–86). These finds point to the existence of underlying cultural formations shared by contemporary communities of the Greek mainland and they decompose arguments in favour of the singling out of the Lefkandi site as only an exception.

Burial practices

Significant evidence for the cultural and ideological developments of the post-Mycenaean era has been provided by the investigation of the burial habits. Despite partial disagreement of scholars (see below) on the causes of these changes, the overall drop in the numbers of excavated burials from that period (Figure 1.2) and differences noted between the different areas of Greece, the emergence of new burial patterns has been widely accepted. The tholos tombs of the Bronze Age which typically hosted multiple burials over the course of several generations have been gradually abandoned – although the case of Thessaly provides evidence for the continuity of the tholos tomb use well into the Iron Age - in favour of single and of much smaller scale cist graves and cremations. Meanwhile, the latter has become a popular choice for the treatment of the dead already from the Protogeometric period in the 11th century BC (Osborne 2009, p. 46). Nonetheless, there does not seem to exist a clear-cut chronological or geographical distinction for the different burial habits as tholos tombs were still being used in certain areas even in the Protogeometric and they have been found in abundance in Messenia and Thessaly including ancient Pherae (Dickinson 1994, Georganas 2000, Lemos 2002, pp. 173–178).

Moreover, the Protogeometric burial contexts point to changes in the depositional patterns as typically fewer grave offerings characterised by the absence of armoury grave offerings, in particular, have been deposited in the 12th and early 11th centuries BC, while an increase in animal sacrifices has been attested in post-1050 BC burial contexts (Osborne 2009, 46). Nonetheless, contemporary grave assemblages do point to certain developments happening in the social structure and organisation as, for example, noted in Athens where the quality of pottery improved significantly during the Protogeometric providing evidence for 'an increasingly ranked [and influential] emerging society' (Dickinson 2006a, p. 3, Osborne 2009, p. 55).

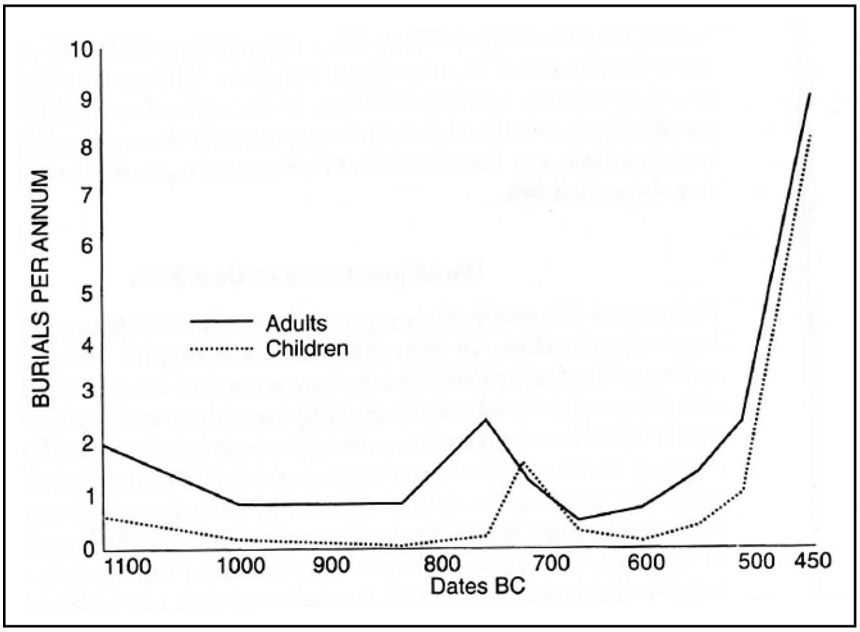


Figure 1.2. The number of adult and child burials in Attica (after Osborne 2009, p. 74, fig. 19b)

On the process of change

Issues of continuity and change at the Bronze to Iron Age transition in Greece have provided fertile ground for extended discussions. In order to account for the changes in the aftermath of the Mycenaean palaces and prior to the 8th century when numbers in the settlements, burials and portable material culture seem to increase, several hypotheses have been put forward and tested against the archaeological record. Archaeological scholarship tended to interpret the changes reflected in the archaeological record of the 12th and 11th centuries BC as too dramatic to have come from processes internal to the local communities. Formulated hypotheses included the coming of foreign, hostile populations including the Dorians and Sea Peoples, changes in the patterns of people's mobility, or environmental factors which possibly led to economic hardship (e.g. Hammond 1931, Weiss 1982, Drews 1993, Frank *et al.* 1993, Cline 2014). Amongst the most debated topics has been Snodgrass' (2000 [1971]) 'bronze shortage theory' which aimed to account both for the palaces' collapse and for the introduction of iron technology (see also below Chapter 2.3.1).

Quite conveniently, literary evidence such as Herodotus' stories on the Heracleidae's return have been interpreted as supporting evidence of the hypothesis of incoming populations and, as also pointed out by Hall, once the link between the collapse of the Mycenaean palaces and the introduction of novel elements such as iron technology, the geometric pottery style or the cremations with the coming of new cultural groups was made it was a matter of time for supporting evidence to be traced in the archaeological record too (Hall 1997, pp. 114–115, Dickinson 2006a, pp. 2–3). However, little support for either a violent invasion or an assimilating migration can in fact be supported by the available archaeological record as more evidence for continuity in regard to space occupation and cultural patterns is identified, for which there is 'no need to provide indications of "Dorian invasion" anymore' (Renfrew 1998a, p. 240). Accordingly, views of external influences have already started to be challenged by the 1970s and 1980s when alternatives to an invasion/migration model included environmental factors such as a 'series of catastrophic droughts' (Stiebing 1980). Finally, it is worth pointing out the oxymoron noted by Dickinson, as the Dorians have been typically seen by the invasion hypothesis supporters as both destroyers and innovators (Dickinson 2006a, p. 3).

In order to account for the apparent population drop in the 12th century and its increase from the 9th and 8th centuries BC onwards as seen in the settlement and burial numbers and which could have been caused by changes in the social formation of contemporary communities, Osborne discussed the possibility for the introduction or abandonment of an age-class system (Osborne 2009, pp. 71–72). This point stems from evidence from the social organisation of Classical Athens and Sparta where individuals were allowed to participate in certain assemblies and/or activities on the basis of their age group. The argument has it that an age-class system would limit the interaction between genders particularly in the crucial young age groups which could have later resulted in the development of stronger homosexual bonds which in turn could have affected the population growth. However and as Osborne himself argues, 'in the current state of the argument, age-classes offer no basis for believing the fertility increase, or indeed that mortality decreased, in these years (Osborne 2009, p. 73). Similarly, Snodgrass has argued for a society relying mostly on pastoral activities which are seen as 'a common form of wealth in insecure environments' rather than on the commercial entrepreneurship of the Mycenaeans' (Snodgrass 1981, pp. 35–36, 2000, pp. 378–380).

Nonetheless, recent and ongoing research has provided increasing evidence for an overall continuity of practice between the LBA and EIA in Greece, emphasising the communities' dynamic internal socio-economic processes which led to new forms of urbanisation, democratisation and colonisation later in the 1st millennium BC. Finally, important aspects of the Protogeometric Greek society still remain to be discovered as proportionately more burial contexts have been unearthed as opposed to settlement sites, and as pointed out by Lemos the absence of evidence alone does not point to negative evidence for social complexity in the post-Mycenaean and Early Iron Age Greece (Lemos 2002, p. 149).

1.1.3 Change is good: Geometric and Archaic Greece

Following the 10th century BC two major transformations took place including the formation of the city-states and the formalization of religious expression as seen in the establishment of the Panhellenic sanctuaries and the erection of monumental temple architecture (Langdon 1987, Coldstream 2003). Meanwhile, the possibility for the circumstances that led to these developments to share some common roots stemming from the post-Mycenaean socio-political organization and the developments brought about during the Geometric period needs consideration.

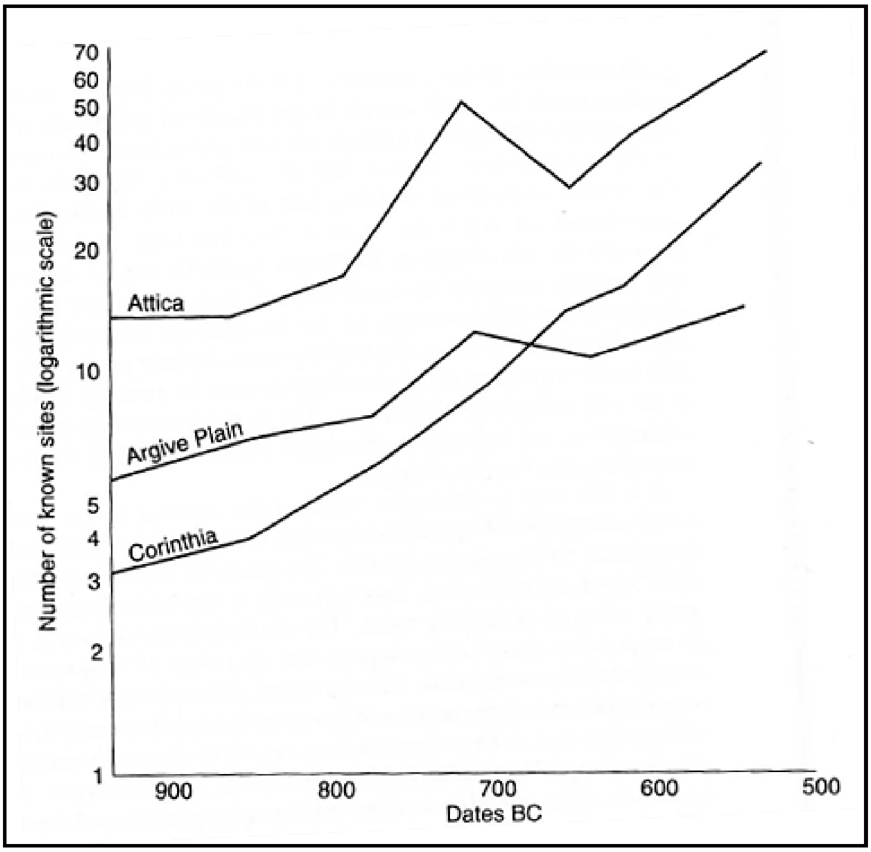


Figure 1.3. The increasing number of known sites in Attica, the Argolid, and Corinthia (after Osborne 2009, p. 76, fig. 20)

As opposed to the post-Mycenaean drop in population and settlement numbers, from the 10th and most markedly the 8th centuries BC site numbers started to steadily increase in the archaeological record down to the Classical period in the 5th century BC. This pattern has been attested in various regions of mainland Greece (Figure 1.3) and the islands, including Thessaly (Gounaris 2009, Osborne 2009, pp. 75–77). In addition to the apparent population rise, emergence of the city-states and the sanctuaries took place in the Early Iron Age. Contemporary cultural developments also included a) the re-introduction of written communication in the form of the Phoenician language system, b) the development of figurative representation in pottery decoration as opposed to the strictly linear-geometric style of the previous period (Figure 1.4), c) the establishment of ritual and competition festivals including the Olympic games [even though cultic activity at Olympia is noted already from the 11th century BC (Eder 2001b)], d) the emergence of new elites and ruling social groups, and e) the establishment and expansion of a network of communications between Greek communities and with the broader Mediterranean region. Nevertheless, even though the contemporary archaeological record is quite extended, a detailed account of the period is outside the scope of this introduction as past research has dealt with the topic in detail (e.g. see De Polignac 1994, Langdon 1997, Lemos 2002, Coldstream 2003, Dickinson 2006a, Osborne 2009).

a) 

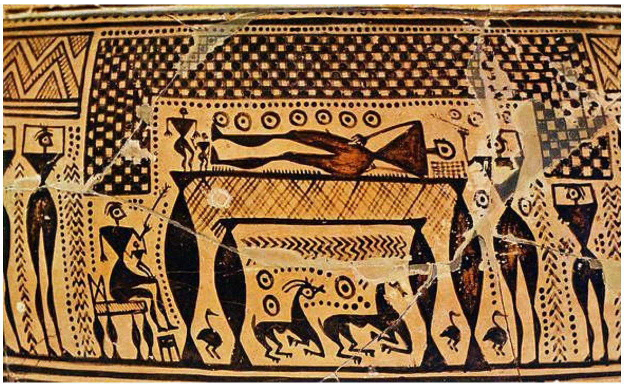
b) 

Figure 1.4. (A) Protogeometric cup decorated with a zone of concentric circles and (B) detail of the Dipylon crater from Athens (c. 750 BC) with a burial ritual scene featuring the exposition and treatment of the dead, i.e. prosthesis

1.1.4 Ancient Thessaly

1.2.4.1 Geomorphology

The physical environment has always had a decisive influence on cultural behaviour and organisation in Thessaly from the very early stages of its habitation in the Upper Paleolithic (Theocharis 1967, Gallis 1996). Located in central Greece, Thessaly is one of the largest plains of the southern Balkan Peninsula. The plain itself is relatively flat and scattered by low hills which geomorphologically divide it into two smaller plains. It is well-irrigated due to the Peneios river, one of the largest rivers in Greek mainland, and surrounded by steep mountains, i.e. Mount Olympus and Mount Ossa to the north, Mount Othrys and Mount Pelion to the south and south-east respectively and the Pindus Mountains to the west (Figure 1.5) which left only a few ways of easy access into the plain, making communication routes and north-south interaction a matter of some importance for Thessaly throughout antiquity (Hansen 1933, p. 13, di Salvatore 1994).

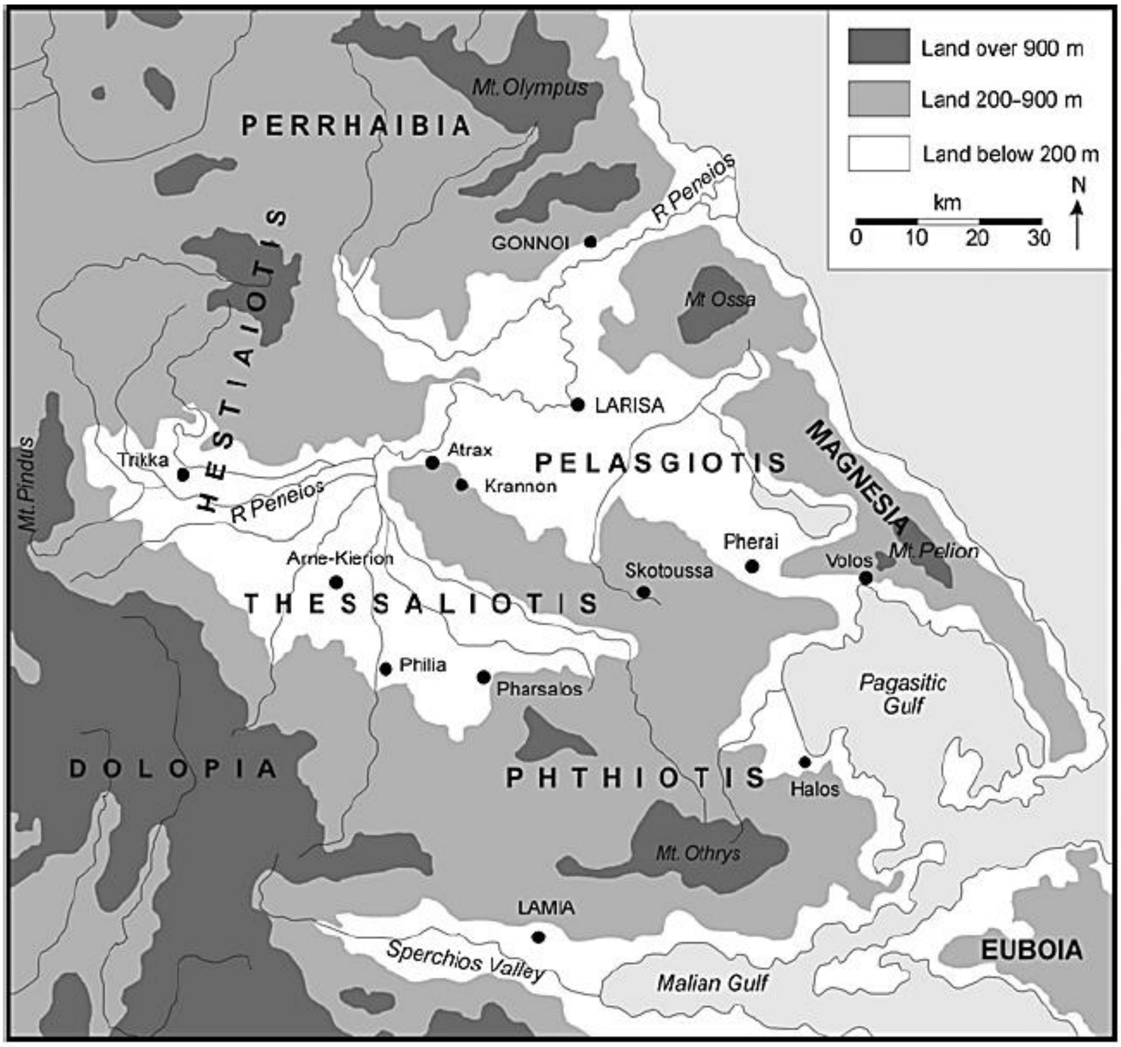


Figure 1.5. Map of Thessaly showing the most important settlements and the tetrarchies division (Hestiaiotis, Thessaliotis, Perrhaibia and Pelasgiotis) (after Hayward, in Morgan 2003, p. 20, fig 1.2)

Despite that the eastern plain of Thessaly is coastal and faces the northwest Aegean Sea, it does not enjoy the assumed benefits of such a position due to the particularly steep and rocky slopes of the eastern coast of Pelion which do not provide safe natural harbours (Westlake 1935, p. 3, Papageorgiou *et al.* 1994, p. 22). As a result, maritime access would have been solely provided through the Pagasetic gulf at the south part of the plain which even in Classical and Hellenistic periods, i.e. prior to sea level rise, would not have been as wide as in modern times (Kampouroglou 1994, p. 46). This apparent isolation also had an impact on the nature of relationships with neighbouring communities and the internal social organisation of Thessaly. However, the plain was relatively self-sufficient and rich in natural resources, ideal for both agricultural and pastoral activities and breading of horses. The latter has been well illustrated by ancient literary sources too, which often refer to the well-known Thessalian cavalry and its determinant role in warfare within and outside Thessaly's borders (Westlake 1935, p. 4, Georganas 2005, p. 73). Overall, life on the Thessalian plain was largely defined by its physical surroundings and natural resources, as well as its changing geomorphology caused either naturally, e.g. the sea level rise, or via human intervention such as the drainage of Lake Boebe or deforestation (Kampouroglou 1994, Papageorgiou *et al.* 1994, p. 22, Archibald 2000, p. 213, Morgan 2003, p. 18).

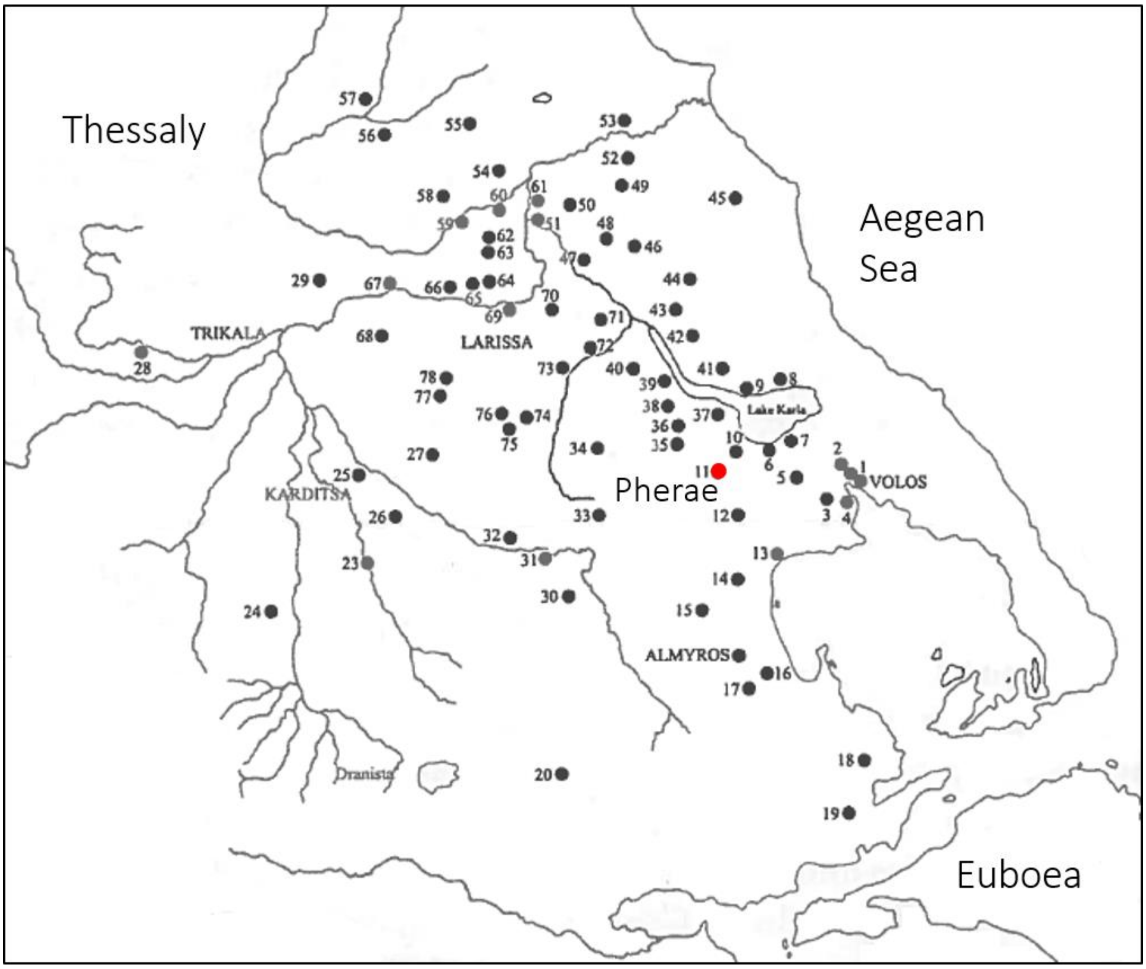


Figure 1.6. Map of the Mycenaean settlements of Thessaly; Pherae is noted with a red dot (after Adrimi-Sismani 2007, p. 174, fig. 15.7)

1.2.4.2 Life and death in Late Bronze and Early Iron Age Thessaly

Bronze Age Thessaly has been traditionally classified as a periphery region of the Mycenaean world, as no palaces equivalent to those in Mycenae, Tiryns or Pylos in the Peloponnese have yet been recovered (e.g. Hansen 1933, Feuer 1983, Rutter 1993, for a review see Adrimi-Sismani 2007). However, such theories for the peripheral character of Thessaly seem not to have taken into much consideration evidence for habitation activity in the plain from the Late Helladic II (1500-1400 BC) onwards when some one hundred Mycenaean sites have been recorded or indeed the presence of locally produced pottery (Feuer 1983, 1994). Nonetheless, recent research has incorporated the Thessalian plain into the Mycenaean world proper and has pointed out 'a powerful and active Mycenaean presence and an important well-structured community' as most of the plain was scattered with settlements (Hope Simpson and Dickinson 1979, Adrimi-Sismani 2007, p. 159) (Figure 1.6). In the post-Mycenaean and the Protogeometric periods, settlement numbers in Thessaly decreased in sympathy with the rest of Greece, but habitation was not overall discontinued. Evidence from 950 BC onwards suggests that human activity was once more growing all over Thessaly, as it did in northern Greece, even though the archaeological record of these communities is not nearly as rich as in contemporary Lefkandi in Euboea (Gounaris 2009, Osborne 2009, p. 55).

Figure 1.7. Map of Thessaly showing the tetrarchies (see Figure 1.10) and subordinate regions (Phthiotis, Achaia Phthioties, Dolopia, Ainis, Malis, and Magnesia) (after Graninger 2011, p. xi)

Thessaly's geomorphology had also considerable impact on its social organization during the 1st millennium BC as it created strong ethnic ties between the plain's communities which further lead to the establishment of a strong central organisation. Partly due to the above, Thessalian communities never formed *poleis* in the strict sense of the term as did settlements in southern and central Greece. All the same, few settlements did develop into powerful towns with central administrative roles that played an important role in later Thessalian history, such as Larissa and Pherae (Wartenberg 1994, Morgan 2000, 2006, Georganas 2008, p. 279).

During the second half of the 1st millennium BC, the plain was well-organized and divided in four main divisions defined by both geographical and political terms. These divisions formed the *tetrads* or *tetrarchies*, namely Hestiaeotis, Pelasgiotis, Thessaliotis, and Achaea Phthiotis, which were controlled by four commanders (*polemarchoi*) or by one in periods of upheaval (*tagos*), and further controlled a number of smaller divisions (the *perioci*) which represented an important part of the Thessalian population (Sordi 1997, p. 207, Archibald 2000, p. 230, Morgan 2003, pp. 18–22) (Figure 1.7). Unification of Thessaly in the form of a federation (*koinon*) took place for the first time in the Archaic period, whereas it was re-established in the early 4th century BC by Jason, the tyrant of Pherae (Helly 1995, Sprawski 2006, Graninger 2011). The latter further highlights the important role that Pherae held in the development and organisation of Thessalian society.

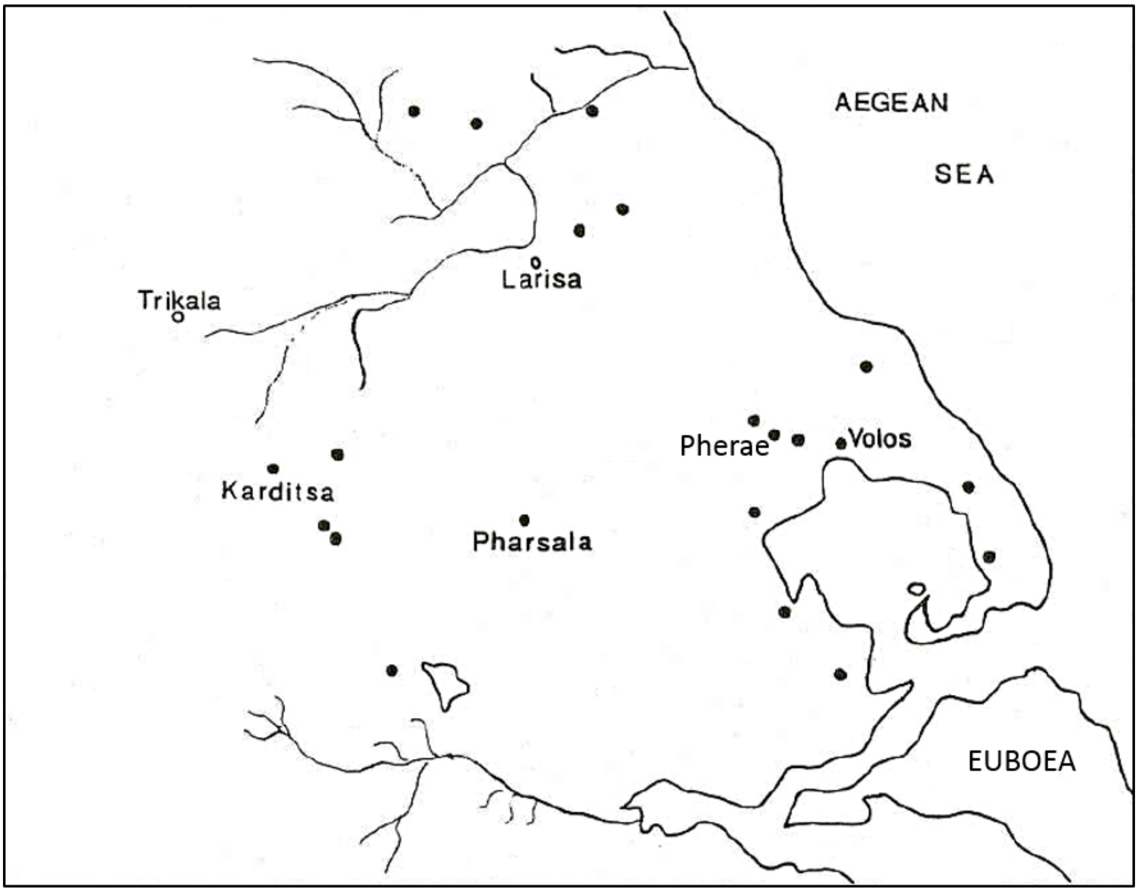


Figure 1.8. Early Iron Age tholos tombs in Thessaly (after Georganas 2000, p. 48, fig. 1); for a map of Mycenaean tholos tombs see Adrimi-Sismani (2007, p. 175, fig. 15.8)

Burial rites in Thessaly

The Thessalian plain was amongst the regions where tholos tombs continued to be used and built in the post-Mycenaean era. They have been constructed as late as the Geometric period as demonstrated by fifty-five tombs recovered so far (Arachoviti 1994, Georganas 2000, 2009, p. 197, Tziafalias and Zaouri 2003, Osborne 2009, p. 35) (Figure 1.8). Nonetheless, these Early Iron Age tholos tombs did not necessarily share the monumental character of their Mycenaean predecessors as their diameter was typically smaller between 2 and 4 m and their entrances were not as elaborate (Georganas 2009, p. 198) (Figure 1.9). In addition, a variety of burial customs were practiced including single inhumation and cremation rites and large tumuli such as those found in Halos cemetery

(Georganas 2002). This intra-regional variety in the burial rituals has raised a discussion concerning the expression of a plurality of Thessalian identities and cultural hybridity, whereas the presence of foreigners has been also proposed in order to account for this variety (for a deconstruction of the latter argument using evidence from Halos see Georganas 2009).

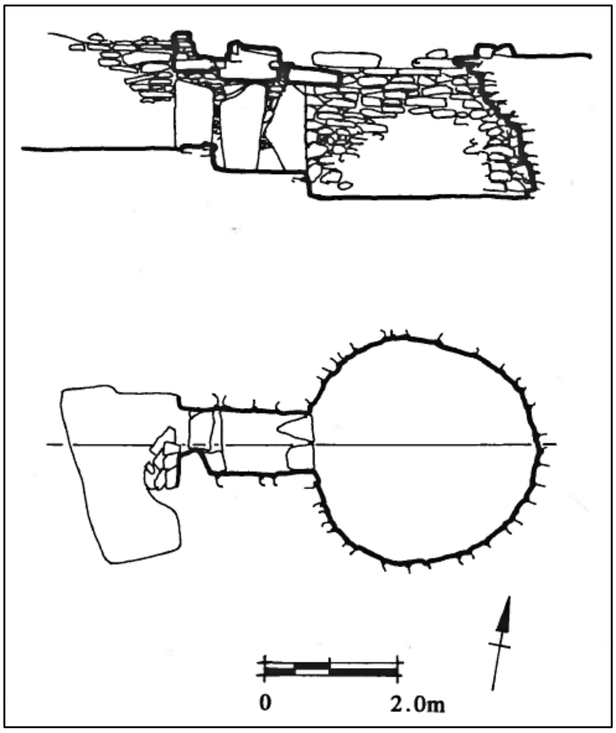


Figure 1.9. Section and plan of a late/sub-Protogeometric tholos tomb found in Chloe near Pherae (after Lemos 2002, p. 176, fig. 18)

Finally, Iron Age Thessaly was renowned as the *par excellence* realm of magic, *'a place of magic and of demonic women'* (Hastings 1908, p. 274, Bowersock 1965). According to ancient literature, the fame of Thessalian 'witches' came to be so widely recognised that by the Roman period the term 'Thessalian' had lost its primary geographical connotation and was often used instead of 'magical' (Phillips 2002, pp. 379–81). Numerous ancient writers mentioned Thessalian women and their skills in the art of healing, possibly due to Mount Pelion's abundance in medicinal and psychoactive plants (Phillips 2002, Brussell 2004), as well as their ability to *'draw down the moon'*, namely the performance of a love charm (Aristophanes, *Nubes* 749) (Hastings 1908, p. 274, Johnston 2008). This shows the important contribution of women in Thessalian society which further justifies the selection of a female deity, namely Enodia, to be the national Thessalian goddess.

1.2.4.3 Ancient Pherae

Ancient Pherae is situated in the eastern and better irrigated half of the plain in the Pelasgiotis district ('tetrarchy') approximately 15 km from the modern city of Volos and some 20 km from Lake Beobe, modern Lake Karla, which was drained in 1962 (Hansen 1933, p. 12, Westlake 1935, p. 6, Margaris *et* *al.* 2006) (Figure 1.5). Pherae's environs facilitated habitation expansion already from the Middle and Late Helladic periods which cover most of the 2nd millennium BC (Adrimi-Sismani 2007, p. 171). The ancient settlement was organized around an acropolis which consisted of two tells (*magoules*), namely Magoula Bakali and Ayios Athanasios Hill, and around Kastraki Hill at the northeast of the acropolis (Béquignon 1937, Kakavogiannis 1977, pp. 179–185) (Figure 1.10). In the Iron Age, Pherae developed into the second most important settlement both politically and economically, not only in the Pelasgiotis but the whole of Thessaly, after Larissa. Although it never acquired a mature city-state organization, it need not necessarily be considered a less complex or less dynamic community than the *poleis* and it can be described as a *big site* in Morgan's sense of the term which encompasses social complexity in ethnos regions (Morgan 1996, p. 57, 2000, pp. 197, 210–211).

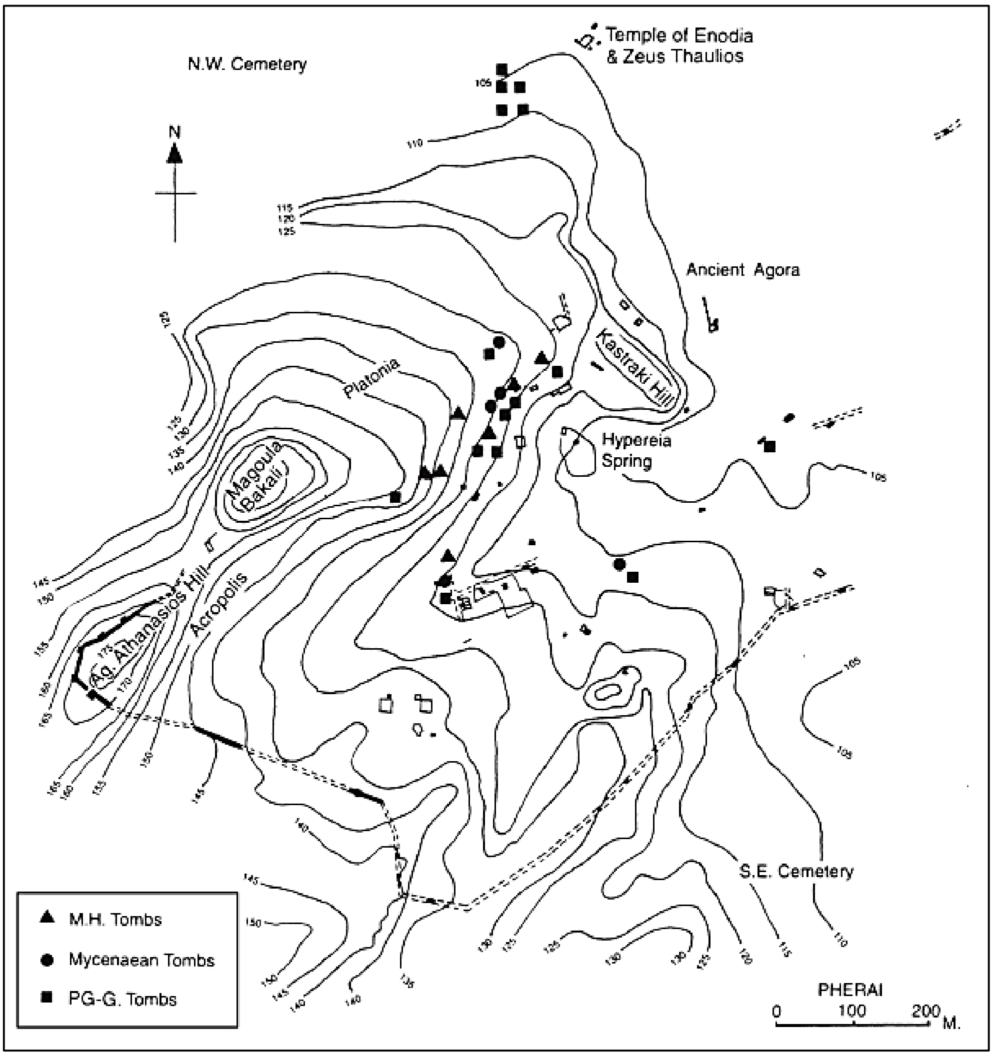


Figure 1.10. Topography of ancient Pherae (after Morgan 2003, p. 93)

First evidence for occupation of the acropolis can be traced already in the Final Neolithic (Doulgeri-Intzesiloglou 1994, p. 77, 2006, p. 100, Arachoviti 2000, pp. 355–357). In succeeding periods, Pherae followed a demographic growth with several expansions of its city plan, even though the evidence presently available cannot argue either for continuity of activity or circumstantial abandonment and re-occupation of the site. However, Pherae gradually gained additional wealth and importance among Thessalian communities mainly due to its proximity to and control of Pagasae (modern city of Volos), namely the only viable port in the whole of Thessaly which served as the seaport (*epineion*) of Pherae until its Roman occupation. Pherae's geographical position on the main communication routes of this otherwise largely inaccessible plain, as well as access to natural resources such as well irrigated lands and Lake Boebe which provided not only access to fresh water but also an excellent environment for waterfowl hunting and fishing were additional advantages for the local community (Hourmouziadis 1982, p. 39, Papadopoulou 1994, p. 106). In addition, Mount Othrys in south-eastern Thessaly is also rich in minerals and, according to Doulgeri-Intzesiloglou (2006, p. 100), the first period of exploitation of the nearby copper ores could be dated as early as the Middle Bronze Age (1900-1600 BC), while small outcrops of copper minerals have been found in close proximity to the settlement on the Chalcodonio Hill (Marcos Vaxevanopoulos pers. com.). Overall, in its most flourishing period in the Hellenistic times, Pherae would have enjoyed control of a sizeable land extending from Chalkodonio Hill to Lake Boebe and Pagasae.

In the post-Mycenaean period, Pherae was the only settlement in the broader region that outlasted the collapse of the palaces as suggested by an uninterrupted stratigraphic sequence into the Protogeometric and Geometric periods (Apostolopoulou-Kakavogianni 1979, p. 199, Doulgeri-Intzesiloglou 2006, p. 100). Despite that the transition period to the Iron Age was a period of decline for the settlement, the latter was stable enough with a record of continuous occupation, while in the Geometric period it had the highest population density in the whole of Thessaly (Apostolopoulou-Kakavogianni 1992, pp. 312–3, Coldstream 2003, p. 327, Gounaris 2009, p. 169). The settlement was finally abandoned in the 1st century AD after falling under Roman occupation in 196 BC, when it was most likely handed over to Augustus as his private property. Until its final abandonment, only small groups of locals remained at Pherae whereas most of the population had moved to Demetrias on the Pagasetic coast (modern city of Volos) which was established in 294 BC having Pagasae as its nucleus (Doulgeri-Intzesiloglou 1994, p. 82, 2006, p. 106).

Overall, the unique advantage of ancient Pherae was the combination of its self-sufficiency, mainly due to its access to natural resources, but also its role as the middleman for the Thessalian maritime trade network. It was a centre of major religious importance and the birthplace of Enodia, a local deity, which came to be considered the national Thessalian goddess. Pherae was an important centre of communications and religious expression, a crossroad of ideas and exchange of cultural manifestations, due to which it has been often treated as an exceptional case amongst Thessalian communities (Béquignon 1937, Hornblower 1986, pp. 128–9, Arachoviti 1994, p. 137, Wartenberg 1994, p. 156).

1.2.4.3.1 Public structures, workshop areas and burial grounds

Additional to residential areas, in Pherae space was reserved for workshops and public structures as evidence from the Archaic to the Hellenistic periods indicates that the settlement was an active production centre too. Traces of a 2nd century BC lead and/or colorants workshop, as well as tuyère pieces and crucible fragments with traces of bronze dating to the Archaic period point to metallurgical production, whereas a Potters' Quarter operated at least during the late Hellenistic period (Doulgeri-Intzesiloglou 1992, 1994, p. 78, Asderaki-Tzoumerkioti and Rehren 2006). Public constructions such as a theatre and possibly an agora, as well as a defensive wall reflect Pherae's bustling social life and its increasing aspirations for control over its neighbours (Doulgeri-Intzesiloglou 1994, p. 81, 2006, p. 102). Finally, in the Pheraean periphery, politically and economically dependent installations primarily of agricultural character existed at least from the Classical period onwards (Chrysostomou 1983, Doulgeri-Intzesiloglou 2000, Stavrakoudi 2006).

Finally, evidence for four burial grounds has been recovered from Iron Age Pherae, as well as several scattered burials in which a wide variety of burial customs was practiced as it was typical for the whole of Thessaly (Adrimi-Sismani 1983, Apostolopoulou-Kakavogianni 1992, pp. 313–4, Arachoviti 1994, Papadopoulos and Kontorli-Papadopoulou 2006) (see also discussion above). Cist and pit graves and tholos tombs seem to have been used simultaneously during the Early Iron Age, and although inhumation was arguably the preferred rite, several cremations have been recovered as well. Meanwhile, burial contexts from Pherae find parallels all over Protogeometric Greece including Thessaly, Macedonia, Attica, Euboea and the Peloponnese (Arachoviti 1994, pp. 126, 137, Georganas 2009).

1.2.4.4 The sanctuary and cult of Enodia

Religious activity at ancient Pherae was characterized by a plurality of major and minor cults as was the norm for contemporary Greece (Mitropoulou 1990, Rakatsanis and Tziafalias 1997). Several gods and goddesses, heroes and mythical characters were worshipped at Pherae including most of the Olympian pantheon, Dioskouroi, Hestia, Heracles, Themis, Cybele, but also the Egyptian Serapis and Isis (Wilamowitz 1931, pp. 173–176, Miller 1974, Chrysostomou 1983, 1994a, 1998, 2008). Central to Pherae was the cult of Nymph Hypereia which was considered a 'benefactor' due to the presence of a fountain which functioned both as a water resource and a place for worship (Béquignon 1937, pp. 5–8).

Patron deity of Pherae was Enodia (in inscriptions both with *-n-* and *-nn-*) to whom the Pheraean sanctuary was dedicated to (Chrysostomou 1998). The sanctuary was situated on the outskirts of the settlement on the Chalkodonio hill, approximately 900 m from the acropolis by the central road to Larissa (Figure 1.11). It was devoted to the cult of Enodia from its very early days, whereas later she was co-worshiped with Zeus Thavlios-Afrios as suggested by inscriptions found on site (Cook 1925, Mitropoulou 1990, Rakatsanis and Tziafalias 1997, p. 36, Chrysostomou 1998, pp. 231–243) (Figure 1.12). It has been described as a 'polis cult' on the basis of its financial organisation and administration being run by the local community of Pherae (Mili 2014, pp. 99–100). Both inscriptions and literary sources including Pausanias (II 10.7) indicate that the cult of Enodia was first instituted at Pherae and that by the Hellenistic period the cult had spread amongst many Thessalian and Macedonian communities, but also in central Greece, Peloponnese and Attica (Pantos 1981, Mitropoulou 1992, Chrysostomou 1994b, 1998, pp. 85–88). Adoption of the cult of Enodia by foreign communities has been typically attributed to either travelling Pheraean citizens or to visitors of Pherae (Chrysostomou 1994b, p. 340). The presence of this great sanctuary and the wide spread of its cult were also strong manifestations of Pheraean authority and territorial sovereignty (De Polignac 1994, p. 3).

Figure 1.11. View of Magoula Bakali from the temple of Thavlios Zeus (north-east)

Enodia was the daughter of Demeter, goddess of harvest and fertility, and Zeus Katachthonios (= 'of the underworld') or the mythological king of Pherae, i.e. Admetos (='untamed'). Although the origins of this cult can be traced back to Mycenaean times, she has been often mistaken for other deities with similar characteristics such as Hekate, Artemis or Vrimo (Wilamowitz 1931, Clement 1932, 1939, p. 200, Kraus 1960, Miller 1974, Rakatsanis and Tziafalias 1997, Chrysostomou 1998, pp. 187–228). However, Enodia encountered outside Thessaly and Macedonia has been assimilated with Artemis (Mili 2014, p. 147).

In the cult of Enodia several important aspects of urban and rur al, personal and public life were embodied. She was the goddess of the underworld, of demons and ghosts, and as suggested by her name itself (En*odia*, 'odos'= road), of the roads and crossroads and protector of travellers. Meanwhile, similar rural cults have been often consecrated to divinities who presided over the crossing of thresholds in life, such as Artemis, Apollo, Hera or Poseidon (De Polignac 1994, p. 8). As expected for a Thessalian goddess, she had magic powers and she possessed the art of *pharmakēa* (= 'the art of healing), whereas according to Westlake (1935, p. 39) she marked the boundary between *'formal and magical cults'*. She protected humans from both accidents and illnesses, but also from the unseen dark demons that could cause harm. She was also *Kourotrophos* (= 'who provides with nourishment/ growth'), responsible for the upbringing of her votaries (García Ramón and Helly 2007). Nonetheless, Enodia had a dark side too; she was a revolting goddess that had to be propitiated through certain ceremonies and expiation rituals after which she became once more charitable and friendly (Chrysostomou 1998, 2008). If, on the other hand, she was not pleased she could release the evil demons against men, during night or daytime. Bearing in mind that chthonic ceremonies were often nocturnal (Panvini 2008) and the 'moon drawing' charm practiced in ancient Thessaly, one should not exclude the possibility of cult being practiced after sunset at the sanctuary of Enodia. Her broad spectrum of expertise, along with Pherae's social and political influence, made Enodia the perfect candidate to become a Thessalian goddess already from the mid-5th century onwards (Sprawski 2006, Georganas 2008). Even though not a member of the Olympic pantheon herself, she enjoyed exceptionally equal treatment (Miller 1974, Morgan 2003, pp. 135–136).

Zeus Thavlios (or Phonios*, φόνος*= murder) was the 'punisher of the murderer' and his cult is attested only in Thessaly. He was the god who killed – mostly animals though – and he who purified the *miasma* of murders (Rakatsanis and Tziafalias 1997, pp. 37–8, Chrysostomou 1998, p. 266, Mili 2014, p. 111), such as in the case of Apollo who was expelled to Thessaly for eight years after killing the Python or the Cyclops (Burkert 1983a, p. 115, Chrysostomou 2008, pp. 266–7). In the transition from the Geometric to the Archaic period a greater emphasis on purification caused by the fear of pollution is seen in the mythological tradition (Burkert 1983b). Zeus at Pherae was also god of the dead and the underworld, as was his partner Enodia. Zeus Afrios, on the other hand, stood for the fertility of trees and vines, cultivation and plant growth (Chrysostomou 1998, p. 232).

Figure 1.12. Votive stele from the sanctuary of Enodia in Pherae where Zeus Thavlios-Afrios is mentioned (θαυλιω/αφριω) (after Chrysostomou 1998, pl. 35a)

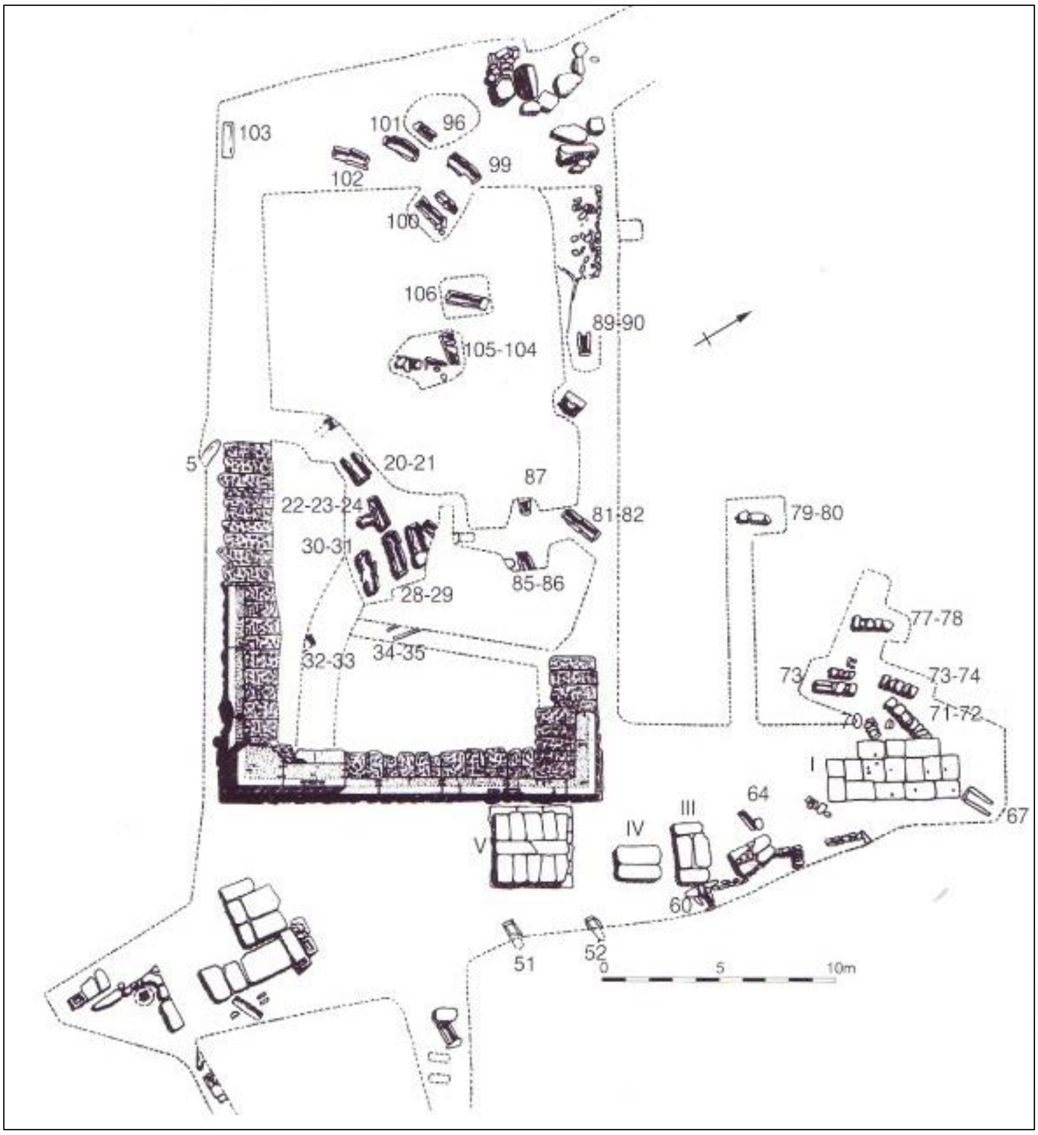


Figure 1.13. Plan of the Protogeometric necropolis and the 4th century temple (after Béquignon 1937)

1.2.4.4.1 Construction phases

Prior to the Enodia sanctuary's establishment, in the Protogeometric period the site was used as a necropolis where approximately 40 cist graves have been so far excavated (Figure 1.13). The graves, mainly inhumations, are generally poor in finds, and often multiple burials were found in a single tomb (Béquignon 1937, pp. 50–56). It has been argued that possibly a tumulus stood in the cemetery since tombs seem to follow a radial pattern possibly pointing to the existence of a central structure (Kalligas 1992, p. 300), while this suggestion is presently difficult to verify. The cemetery's activity covers only the Protogeometric period, whereas the sanctuary of Enodia was established soon afterwards. Although it is safe to put its establishment in the Geometric period, it is difficult to date it more accurately on the basis of the archaeological record (Snodgrass 2000), and both the Early and Late Geometric periods have been suggested (Chrysosotmou 1998, p. 268, and Coldstream 2003, p. 207 respectively), whereas its use was continuous until the Hellenistic and possibly Roman times (Béquignon 1937, Stahlin 2002). Finally, the establishment of the sanctuary and its rich votive record have been often considered amongst the earliest manifestations for Pherae's influential role within Thessalian communities (Doulgeri-Intzesiloglou 2006).

Figure 1.14. Part of the temple's krepis showing Archaic material (column fragments) used in the foundation of the Hellenistic construction

Prior to the 6th century, cult was practiced in the open air as in most early Greek sanctuaries and no early architectural structures have so far been found (Béquignon 1937, pp. 43–47). However, Arvanitopoulos (1925) on the basis of the wealth of finds proposed the existence of an early structure, possibly a temple built from perishable material, such as mud-bricks and wood. Such structure has not yet been confirmed by excavations, yet the hypothesis is worth consideration.

Nonetheless, even in the very early period of use of the sanctuary there must have stood a chthonic altar that could have also been related to the Protogeometric cemetery and would have been the focus of worship and sacrifice (Rupp 1983, p. 101, Chrysostomou 1998, p. 38). Evidence for the first temple constructed on site dates no earlier than the 6th century BC of which only construction material re-used in the erection of the second temple in the Hellenistic period remains (Østby 1994, p. 139) (Figure 1.14). Both the 6th and the 4th century BC temples were Doric peripteral made of limestone (Béquignon 1937, Chrysostomou 1998). The second temple whose foundations are still visible today (Figure 1.15) is larger than the earlier one and it is heavily indebted to Classical Attic architectural models. It is technically closely related to the temple at Ramnous and of Apollo at Delphi whose technical details and principal dimensions it repeats reduced by one third. These architectural similarities between the Pherae and Delphi temples are such that Østby (1994, p. 142) has suggested they could have been constructed by architects and workmen of the same tradition, if not by the same individuals. He dates the Pheraean temple at around 300 BC, i.e. within a lifetime from the erection of temple of Apollo at Delphi (330 BC). Possible connections with the Delphic temple have to be understood in cultural rather than religious terms due to the close political ties that existed, while cultic activity at the two sites had very little in common. Finally, the adoption of existing models should rather be considered as a conscious decision on the part of the Pheraeans (Østby 1992, p. 85, 1994) pointing to the settlement's exercised authority and its openness in new cultural expressions.

Figure 1.15. View of the Hellenistic temple at the sanctuary of Enodia from the east

1.2 The role of sanctuaries in early Greek society

In the course of the 8th century BC an enormous increase in votive offerings, and bronze offerings in particular, took place at Pherae, as at many sanctuaries around Greece and the eastern Mediterranean. This cannot be wholly explained by population growth alone, but rather as a shift in cult practices. In order to account for this phenomenon a distinction between local sanctuaries attached to a particular settlement or emerging polis such as the temple of Enodia and Thavlios Zeus at Pherae and those larger, intra-regional sanctuaries, like Olympia and Delphi, which were already on the way to becoming Panhellenic should be made, as not all sanctuaries fulfilled the same social functions (Coldstream 2003, p. 338).

Emergence of the first cult sites which would later develop in the great sanctuaries of early Greece can be traced as early as the 10th century BC (Mazarakis Ainian 1988, p. 10, Niemeier 2013). Although religious expression of early Greece in its maturity came to form a quite distinct aspect of Iron Age society, it largely developed from surviving elements of the preceding Mycenaean tradition which played a decisive role in the shaping of certain cult practices of the Protogeometric, Geometric and Archaic periods such as the emergence of the Olympian pantheon and a number of outlasting cults and festivals (Dietrich 1983, Dickinson 2006b, Cosmopoulos 2014). The above highlights further the blurred cultural boundaries between Mycenaean and Early Iron Age tradition while any patterns of change need not be either exclusive or antagonistic or, in fact, universal (De Polignac 1994, p. 8) (see also above this Chapter 1.1.1). All the same, certain elements were introduced in the Iron Age cultic practice including the transformation of the open-air cults to well-organised and managed sanctuaries. Cult in these sanctuaries was initially practiced in the open-air, whereas temples were gradually erected as a result of communal investment and communities' decisions over monumentalisation and formalization of cultic practice (Marinatos 1993, p. 228, Morgan 1993, p. 19). The emergence of free-standing temple architecture can be dated to the beginning of the 8th century BC (Rupp 1983, Voyatzis 1990), although dates vary at the different sites.

In addition, certain dedications themselves lack close Mycenaean predecessors such as bronze horse figurines which were rather a product of the Geometric period. Furthermore, it is from the break of the 1st millennium BC onwards that wealth is offered to gods rather than the ancestors as illustrated in the shift in the depositional patterns of votive offerings and their accumulation in the sanctuaries instead of burial contexts (Coldstream 1983a, Morris 1986, Snodgrass 1990). Hence, gods were receiving an increasingly high proportion of the wealth available including a significant amount of the metal artefacts in circulation at least during the Geometric period (Coldstream 2003, p. 338). Finally, the reasons these particular sites were selected for the establishment of the sanctuaries, although much discussed, are yet not sufficiently understood.

Early Iron Age Greek sanctuaries served multiple social roles and engaged their visitors in more complex ways than just in the form of religious expression (Scott 2010). Situated on the frontiers between neighbouring city-states/communities they contributed in the consolidation of political and economic power of the local ruling classes (De Polignac 1994). They have been also supposed to neutralize the borders by providing safe meeting points for locals and travellers alike. By providing asylum they facilitated trade and safe cross-over, almost like 'sacred channels', marking preferable passages (Sinn 1993, 1996). Meanwhile, it could be argued that busy crossroads have been purposefully chosen for their establishment as they were also important foci of economic transactions (Sinn 1996, p. 68). They sustained a supply and demand network and stimulated production of certain commodities through local festival markets and by encouraging religious depositional behaviours which, albeit seasonal, provided craftsmen and traders with a dependable work field (Linders 1992, p. 11).

Overall, sanctuaries had a rather independent economy and a high level of organization at least from the late 8th and 7th centuries BC reflecting similar conditions of contemporary emerging city-states (Strøm 1992, p. 50). They also established a sacred landscape which was often central to the developement of the *polis* (De Polignac 1984, p. 3, Alcock and Osborne 1994, p. 1). In addition, their role in the standardisation of Iron Age cult practice, including the depositional fashion of offerings, expressions of art and architecture, was decisive via their influence over a large part of the Greek world as, for example, seen in the sanctuaries of Olympia, Delphi, Delos and Samos (Langdon 1987, p. 107). Early Greek sanctuaries eventually developed into a form of *state* themselves, and they facilitated expressions of regional competition and the interaction of both local and foreign aristocracies (Mazarakis Ainian 1988, pp. 113–115, De Polignac 1994).

1.2.1 Sanctuaries and Metallurgy

During the Early Iron Age, a special relationship between religious space and metal production developed in the eastern Mediterranean and the Greek region during the Early Iron Age. Such rapport can be traced back already to the Bronze Age when metallurgical and religious inter-connections have been quite prominent in eastern Mediterranean including Cyprus, the Levant, Egypt and Crete (Psaroudakis 2003, Kassianidou 2005). It has been argued that the relationship between metallurgical and cult practice was deep rooted, supported by a strong ideological background, and that it involved more than just a geographical co-occurrence (Knapp 1986). Even though the Near East has been particularly renowned of this phenomenon possibly due to richer mineral deposits and a more powerful priesthood, it was an important aspect of the Greek world as well (Schallin 1997, Psaroudakis 2003).

Mainland Greece and the Aegean had engaged in similar production activities as indicated by the Linear B clay tablets from Pylos with reference to bronze being stored within sacred space (Hiller 1979, Hägg 1992). In the context of the 1st millennium BC, metalworking and the production of metal artefacts were important features of early, as well as later Iron Age Greek sanctuaries (Strøm 1992, p. 49). They were closely related to the main activities taking place at the sanctuaries, such as the production of votive dedications, temple adornments and utensils for performing rituals, but also the construction and maintenance activities on site including the construction of the temple itself (Risberg 1997, p. 185). Evidence of metalworking in Greek sanctuaries has been so far located in a number of sites including Olympia, Bassae, Tegea and the Argive Heraion in the Peloponnese, at Kalapodi, Delphi, Eretria, Philia and ancient Pherae in central Greece; at Delos, Aegina, and the Samian Heraion in the Aegean, and at Aetos on Ithaka in the Adriatic (Kilian 1983, Schneider 1989, Risberg 1992, 1997, Felsch 2007). Traces of these metalworking activities, though not necessarily all present on a single site simultaneously, include metal and stone metalworking tools, casting moulds, semi-finished and miscast objects, as well as metallurgical debris and slag fragments.

Geometric sanctuaries in both polis and ethnos states have yielded activity of local workshops with characteristic typologies such as the distinct regional styles of Corinth, Olympia, or Arcadia (Coldstream 1983b, Voyatzis 1990). The earliest metalworking remains recovered from sanctuary contexts date to the Protogeometric and Geometric periods when overall intensity of activity took place (Risberg 1997, p. 185). Even though traces of metallurgical activity are more frequently found in later periods, it is reasonable to argue that early activity must have taken place in a number of other sanctuaries as well such as at Olympia and Kalapodi, since metallurgical waste in the archaeological record could have easily been misinterpreted and mistakenly evaluated as unimportant. Nonetheless, this phenomenon's unmistakable evidence is the deposition of thousands of metal objects themselves in the sanctuaries all over the eastern Mediterranean which in itself is a strong argument for the sanctity of this material form.

Overall, the production of metal objects required considerable investment and the ability to procure the raw materials and know-how on the part of Greek communities. Furthermore, the circulation and religious deposition of these commodities was a key aspect of Early Iron Age Greek society as it was used by its ruling class as a means to control the gift exchange system and by extension a means to maintain socio-political and economic balances, as well as to gain and secure social standing, influence and control (Risberg 1997, p. 191, Psaroudakis 2003, pp. 584–5) (see also Chapter 9).

1.2.2 Bronze artefacts in the divine realm

The large number of metal artefacts deposited in Early Iron Age sanctuaries marked a rather generalised shift towards time-proof and durable material forms in contemporary religious practice as expressed in the re-emergence of monumental temple architecture. In the course of the 8th century BC an enormous increase of unprecedented scale in the deposition of metal and copper-based votive offerings took place in Greek sanctuaries. This increase was quantitative as it was also qualitative and changes in the depositional fashion cannot be sufficiently understood simply in terms of wealth accumulation or population growth (De Polignac 1994, Coldstream 2003, p. 338). In addition, not only was a greater proportion of wealth was being dedicated, but it was being done so by individuals from a wider range of social groups than in the Bronze Age (Morgan 1993, p. 19, Marakas 2010).

Conversion of the offering into a durable and, thus, memorable material form transformed sacrifice into a memorable gesture and an action of wealth demonstration for the sanctuaries' visitors (De Polignac 1994, p. 12). Prestige offerings, such as the tripod cauldrons, mark the phenomenon of ritualized social competition which expressed and influenced the local conflicts for power among neighbouring communities and their aristocracies. Meanwhile, all metal dedications were both manifestations of religious gratitude, but also a powerful way of expressing one's status, establishing authority, and acquiring social recognition (Risberg 1997, p. 191, Bremer 1998). Moreover, metal objects should be taken as having strong symbolic and transcendent properties which cannot be ignored (Psaroudakis 2003, p. 585). In fact, as suggested by Bouzek (1997, p. 112) all Macedonian bronzes, namely a typological group of copper-based artefacts with links to the Balkans and particularly the north west part of the region (see also Appendix I, Figure I.29), were considered to be of some magical, talismanic character, which, if so, would explain their popularity as dedications to the Greek sanctuaries including the one at ancient Pherae. The practice of votive dedication of the metal artefacts has been amongst the main reasons for their circulation across Greece and the Aegean at the beginning of the 1st millennium BC as the sanctuaries functioned as points of trade and cultural contacts too (Coldstream 1983a, p. 201).

Bronze artefacts were dedicated either in their own right or as a tangible memento of a sacrifice performed. They were often dedicated accompanying the offering of an animal or other consumables suggesting an immediate link of the metal artefacts with the ritual acts (Bergman 1987, Brize 1988). Fibulae, for instance, as with other types of dress accessories have been often dedicated along with textiles and garments typically in sanctuaries dedicated to female deities (Lee 2015, pp. 127–128, 219) such as Enodia in Thessaly. The *peplos* dedicated to Athena during Panathenaia during the Classical period would be a characteristic example of garment dedication. It was through these metal objects that the actual action of sacrifice would be remembered. Choice of offerings would have been made on the basis of their symbolism, namely what they stood for and the meaning they communicated to other participants; their appropriateness as a gift to a powerful god or goddess was determined by the special relationship with the respective deity or even as '*agalma'*, a beautiful thing to be appreciated and enjoyed by the recipient (Alroth 1987, p. 18). An offering could be anything from an object of everyday use, such as dress ornaments or jewellery articles, to objects made exclusively for votive use, such as the tripod cauldrons and animal figurines (Figure 1.16). This implies a marked difference in the nature of the bronze offerings between the Late Bronze Age and the Geometric period when not just a selection of the most elaborate or exotic goods were considered suitable for religious deposition, but rather artefact types of a much broader typological spectrum with various functions (Langdon 1987, p. 108).

Figure 1.16. Fibulae and bird pendants from the sanctuary of Enodia at the National Archaeological Museum in Athens

Once the bronzes were deposited, they unavoidably entered the gods' realm and were not to return to the secular world. It was considered of the outmost importance that none of the goods which entered the sanctuary should be lost or re-enter circulation. Reuse of metal votive offerings was rare at least as late as the 5th century BC and even then inventories specified that objects may be remelt and reshaped (Linders 1987, p. 117). The above tradition resulted in the massive accumulation of material in the sanctuaries. As votive offerings accumulated over long periods of time and when shortage of space occurred they were kept in special deposits within the consecrated space, as in the case of Pherae. Although any attempt to establish the peak or the frequency of the above ritual practice would be quite bold, it is generally accepted that it was rather popular at least for the first half of the 1st millennium BC and the Geometric period (Aleshire 1992, Linders 1992).

Individual objects in votive deposits do not seem to have been exclusive to any particular type of cult, either Olympian, chthonic or heroic. There is a characteristic lack of systematic differentiation and specialization in the depositional record of early Greece. Identical or similar objects could be offered in almost all types of cults and on several occasions of different nature. For instance, the remarkable similarity of the material from the sanctuaries of Enodia in Pherae, Athena Itonia in Philia, and Artemis and Apollo in Kalapodi, to name a few is indicative of this tradition of shared cult practices (Felsch 1983, 2007, Kilian-Dirlmeier 1985, Intzesiloglou 2006). Ancient Greeks were happy to give to the heroes the very same gifts that they offered to their dead or to their gods. For instance, a tholos tomb in ancient Pherae contained metal offerings of the same types as found at the nearby sanctuary of Enodia (Hägg 1987, p. 99, Arachoviti 1994).

Finally, even though the ritual deposition of bronze offerings was widespread in the whole of the Mediterranean from Asia Minor to the east and to Italy in the west (Orlandini 1965, Morgan 1993, p. 18), this custom has been most extensively practiced in the Greek world. This phenomenon can only be fully understood if seen as related to the previous Mycenaean tradition (see also above this Chapter 1.2). For example, on the basis of the record of Mycenaean metal votive offerings found in south-eastern Thessaly, Hourmouziadis (1982, p. 68) has suggested that religious deposition of large amounts of metal objects during the Early Iron Age was the continuation of an old custom tracing back to the Late Bronze Age. Nonetheless, even though Early Greek votive activity resulted from the accumulation of successive changes and transformations in cultural and ritual expression, the result itself had little in common with its Bronze Age origins (Dickinson 2006b, p. 116).

1.2.3 Votive offerings as gifts to the gods

Grasping the full spectrum of the feelings entailed in the Early Iron Age religious expression and by contemporary participants including the pilgrims and sanctuary administrations, is indeed challenging as no literary records are available for this period. Meanwhile, there is evidence to suggest that religious doubt in ancient Greece did not challenge the existence of gods themselves or their corporeality. Worshippers' concerns had rather to do with the gods' interest in human affairs and how to successfully communicate in order to appease them rather than in their mere existence. Furthermore, the understanding of these religious sentiments is challenging in the context of a modern, rather secularised way of thinking (van Leuven 1981, p. 12, Parker 1998, p. 114). Ancient votive deposition is often interpreted as a form of material wealth and power display of local elites. However, interpretations should not diminish the sacredness of these acts or any feelings of submission to transcendent powers and the supernatural link developed between giver, gift and receiver (van Wees 1998, p. 26, Erdman 2012). Acts of religious offering are complex and should be seen as the end of a chain of an exchange involving both secular and transcendent parties whose nature is as variable and unique as the agents involved (De Polignac 1994, p. 6).

Votive offerings were objects dedicated to supernatural and often feared powers, for a number of reasons such as to ask for something in return, as a thanksgiving for kindness already received, or in order to seek forgiveness for some lawless act. Expectations of reciprocity of this kind were based on an assumed reality than hopeful expectations (Parker 1998, p. 105). This reciprocal relationship established between the secular and profane spheres was governed by rules of a well-defined gift exchange system. Gift giving either to men or to gods was governed by the same rules and the anticipation of a similar response which are in contrast with late 19th and 20th century ideologies which dictate that a gift is being given without expecting anything in return, as an *'optional extra'*, otherwise it cannot be called a 'gift' (van Wees 1998, p. 28). Nonetheless, this old *'do ut des'* principle is still present in contemporary societies too as revealed from ethnographic studies (Gregory 1980, Burkert 1987, Englund 1987). Similarly, in past societies when no-one would offer anything without expecting to benefit from it. The receiver's obligation to return something of more or less equal value was expected, while failing to do so would threaten social integrity (von Reden 1998, Wagner-Hasel 2006). This expected reciprocity behind acts of dedication aimed to achieve balance within society and was an effective means of 'reducing social anxieties' during the interaction between both local and inter-regional populations (Langdon 1987, p. 109). Nonetheless, a certain degree of asymmetry must have inevitably characterised the transactions between humans and gods (Bremer 1998, p. 127).

Religious deposition of objects was an integral aspect of past societies and the relationship between people and artefacts. It was also one of the most important forms of economic and social transactions. However, research tends to neglect the economic aspects of ritually deposited objects such as when they are published by type and not by context or when they are dealt with as 'works of art' and not for the concepts that they used to signify in the past (Osborne 2004, Plantzos 2011). It has been argued that the numerous offerings found in ancient Greek sanctuaries were dealt with by contemporary societies more as autonomous entities and direct divine representations, rather than as symbols or 'middlemen' of meanings (Whitley 2006). This is more easily understood in the case of anthropomorphic figurines which often represented a deity (Plantzos 2011, p. 27), but such symbolic representations can be extended to other classes of votive dedications as well, such as decorative ornaments and armour.

Once objects were ritually deposited they were interwoven with the supernatural, thus holding a special meaning and importance amongst the context of material culture. An object's possibility to be dedicated alone had an immediate effect on its use as a commodity overall (Gregory 1980, 1982, Appadurai 1986b). Even if objects were made for everyday use and were never dedicated themselves, once they belonged to an artefact type that was suitable for ritual deposition they were 'converted' into items of symbolic value which had an effect on the way these objects were perceived, used and produced by contemporary societies, *'even if they never in fact end up dedicated'* (Davenport 1986, Osborne 2004, p. 2).

To conclude, votive offerings were socially and economically significant, as they were spiritually for early Greek society. Religious ideology was an element internal to the economy of the sanctuary, as well as to social relations of production (Knapp 1986, p. 4). Either emphasizing the offerings' role as vehicles for expression of devotion to establish a relationship with a non-natural person, as alienated items of faith and incarnated signs (Gregory 1980, Appadurai 1986b, Englund 1987) or as durables that cannot be further exchanged, a form of deliberate wealth destruction and as one way of building social prestige and to guarantee social cohesion (Bradley 1982, Davenport 1986, Linders 1987, Godelier 1996), dedicated objects were meaningful for past peoples and communicated complex ideas, and should be treated as such by archaeological research. Nonetheless, models and methods of analysis in order to interpret the polysemic character of offerings, the processes of object consecration and the intentions of the dedicator (Greco 2008) are still negotiated. Investigating the objects' biographies in order to explain how and why diverse groups of artefacts have been deposited within the same sacred ground would be one way forward (Erdman 2012). Finally, the latter is also the stance adopted by the present study and it is further explored below (see Chapter 9).

The above aspects of Early Iron Age Greek society and cult have delineated the socio-cultural context of the copper-based artefacts which consist the focus of the present study as the circumstances around their production and use, both utilitarian and symbolic, have been highlighted. In the second chapter, discussion focuses on the aspects of contemporary metallurgical technology and on the current state of research in regard to the Early Iron Age copper-based artefacts' archaeometric investigation.

Chapter 2. Copper and its alloys in Early Iron Age Greece

Copper and copper alloys have been a significant aspect of ancient communities from the Chalcolithic and the Bronze Age. Archaeological research from its onset (e.g. see the work by Klaproth 1798) has focused on different aspects of metal use, production and circulation in order to address questions of social complexity, cultural contacts and/or the development and transmission of technological knowledge. Scientific examination of Greece and the Aegean has also focused on the introduction of the use of metals and subsequent metallurgical advances and has provided ground for a deeper understanding of Prehistoric and early Greek communities such as the impact of foreign influences in the form of technological advances and/or imported goods. Meanwhile, the study of metals in archaeology has also raised extended discussions and debates amongst the research community such as this of the tin supply and circulation the Old World from the very early stages of its exploitation down to the Roman period (e.g. see Muhly 1998).

2.1 The early use of copper alloys

The use of copper-base objects in ancient Greece has been long and dates well back into the Late Neolithic as evidence form Chios, Rhodes and southern Peloponnese suggest (Mangou and Ioannou 1997, pp. 59, note 2, 63, Gale and Stos-Gale 2008). A crucible with copper prills from Sitagroi in Macedonia points to the production of copper for beads and small objects in mainland Greece from the late 5th millennium BC (Renfrew 1973, McGeehan-Liritzis and Gale 1988). Even though, it has been suggested recently that the use of tin bronzes in the Balkans dates in the 5th millennium BC (Radivojević *et al.* 2013, 2014), in the archaeological record of Greece tin bronzes are to be found from the Early Bronze Age in the 3rd millennium BC as indicated by a number of objects recovered from several regions in the Greek mainland and the islands such as from Kastri on Syros and Thermi on Lesvos in the Aegean, Agios Kosmas and Manika in central Greece, and Lefkas in the Adriatic Islands (Mylonas 1959, Stos-Gale and Gilmore 1984, Sampson 1985, McGeehan-Liritzis and Taylor 1987, pp. 292–294, Stos-Gale 1992, p. 164, Muhly 1999, p. 15). However, a generalised use of tin bronzes took place only later in the Middle Bronze Age when it gradually replaced arsenical copper, which until then was the main metal produced (Craddock 1976, Charles 1978, Mangou and Ioannou 1997, 1998, 1999, Kayafa 2006, Papadimitriou 2008). In the transition period from the use of arsenic to that of tin as the main alloying agent of copper, both alloys, namely tin and arsenical bronze, were being used simultaneously (Mangou and Ioannou 1999, p. 99).

The earlier use of arsenic as opposed to that of tin could be explained by the relative abundance of arsenic minerals, as well as its more likely co-occurrence with copper minerals in sulphide deposits, i.e. copper arsenates, and it must have resulted from the smelting of such polymetallic ores rather than intentional mixing (Earl and Adriaens 2000, p. 14, Cathro 2005, Radivojević *et al.* 2013). Similarly, early tin bronzes could have emerged as part of the experimentation in a polymetallic context involving other metals such as arsenic, lead and silver, gold, antimony, and iron, such as stannite (Cu_2FeSnS_4) (Charles 1978, Wertime 1978a, p. 2). Nevertheless, this sequence in copper alloy use is not a linear development as indicated by particularities in alloy recipes between mainland Greece, the Aegean and Crete during the Bronze Age. During the Early Bronze Age, for example, there is significant evidence for the practice of copper metallurgy within the Aegean region, while Cretan metallurgy remained in the background and it only flourished in the Middle Bronze Age (Renfrew 1967, pp. 1, 13–14, Branigan 1982, Mangou and Ioannou 1998, pp. 91–92, 95, 1999, p. 81, Georgakopoulou *et al.* 2011).

Lead as an intentional addition in copper alloys started to be used in Greece from the Late Bronze Age onwards (Mangou and Ioannou 1998, p. 98, 1999, p. 90, Papadimitriou 2008, p. 285), whereas its systematic use and a better understanding of its particular properties took place from the Early Iron Age onwards. Leaded alloys were increasingly used from the late Geometric and early Archaic periods particularly during casting due the metals increased fluidity, while by the Hellenistic period the use of leaded bronze for castings, including life-size bronze sculptures, was the rule (Craddock 1977, Papadimitriou 2001, Kayafa 2006). During the 1st millennium BC the use of various copper alloy recipes with deliberate additions of both tin and lead, and the metalworking techniques was widely practiced for the production of a variety of artefact types of both decorative and utilitarian character.

2.2 The archaeological record of copper mining and related metallurgical activities

Greece and the Aegean are relatively rich in minerals that would have sustained local metal production throughout antiquity. However, this region is lacking deposits of tin, a metal as necessary as copper for the production of the vast majority of the copper-based artefacts from the Middle and Late Bronze Age onwards (see also discussion below) (Mangou and Ioannou 1997, 1998, 1999). Copper ores that have been exploited in different periods of antiquity have been found in several parts of mainland Greece and the Aegean such as the Laurion district in Attica, Mount Othrys in southeast Thessaly, Euboea, and several of the Cycladic islands such as Serifos, Kea and Kythnos (Voreadis 1954, Gale and Stos-Gale 1982, Papadimitriou *et al.* 1992, Papastamataki 1994, Papastamataki *et al.* 1994, Mangou and Ioannou 1997, Gale *et al.* 2009, Georgakopoulou *et al.* 2011). Moreover, the *Naval Intelligence Geographical Handbook* (1944) lists over seventy copper ore deposits on mainland Greece (Gale and Stos-Gale 1982, p. 17) (Figure 2.1). In addition, the numerous small outcrops of copper mineralisations that would not be considered as 'ores' in modern terms and, thus, would not have been included in 20th century geological and mineralogical maps need also to be considered (Gale *et al.* 2009, p. 162, Georgakopoulou *et al.* 2011, p. 140). Such outcrops that have been most probably visible during prehistory would have been exhausted by the intensive modern or even during ancient mining activities over subsequent periods (Renfrew 1967, p. 13). In the case of Serifos, for example, copper veins that were visible in the late 19th century and that have been described by Kordellas (1878), have been exhausted by 1950 (Papadimitriou and Fragiskos 2008, pp. 529–530). Finally, copper used during Greek antiquity could have equally come from local ores, as well as from trading activities with other copper production centres such as Cyprus.

2.2.1 Archaeological evidence and its dating

Defining the periods of exploitation of copper ore sources in mainland Greece during antiquity is a rather challenging task even when traces of mining and primary production are evident. This is not only related to the aforementioned subsequent periods of certain sites, but also due to limitations of metallurgical analysis itself. It is most often that metallurgical sites are characterised as such on the basis of the presence of slag heaps and are typically dated from surface pottery finds, whereas explorative excavations of mining sites in Greece are rarely available. In addition, sampling strategies of metallurgical waste products often include surface, loosely dated finds as in the cases of slag analysis from Pelasgia, Phocis and Mount Othrys in central Greece (Papadimitriou *et al.* 1992, p. 208, Papastamataki *et al.* 1994, p. 248, Mangou and Ioannou 1999, p. 82, Tizzoni *et al.* 2008). Furthermore, it is not unusual for the pottery recovered from such sites to be attributed to different chronological periods in the Bronze and Iron Ages, thus making the establishment of chronologies for the metallurgical waste even more problematic. The same often applies to mineral outcrops with evidence of ancient activity. For example, it is indicated by the analysis of slags from Pelasgia in southern Thessaly that exploitation of local ores in central Greece took place during the Classical, Hellenistic and Roman periods, but possibly even earlier during the Late Bronze Age, thus potentially covering a large time span (Papastamataki and Dimitriou 1987, p. 587, Papadimitriou *et al.* 1992). Even within the scope of the large scale lead isotope enterprise that took place from the 1980s onwards that was mainly led by the work of Gale and Stos-Gale, little attention was paid to the dating of the mining sites themselves and production centres remained *'undated and practically unstudied'* (Georgakopoulou *et al.* 2011, p. 123).

Even though it is certain that ancient activity took place on several mining sites such as those of the Laurion district and Serifos, modern exploitation and the reprocessing of slag heaps most often hinders a precise dating for the different periods of metallurgical activity (Gale *et al.* 2009, p. 161, Georgakopoulou *et al.* 2011). Characteristic of this situation is the comment of Papadimitriou and Fragiskos (2008, p. 530) for the Serifos outcrops that *'copper has been produced at some period in antiquity'* on the island which acknowledges ancient mining activity but cannot provide a chronological framework. It was not until the mid-2000s that more targeted studies of specific, often stratified metallurgical sites took place that contributed to a better understanding of the different aspects of metal production, both technological and socio-economic, in more defined chronological periods such as the Bronze Age sites of Chrysokamino in Crete and Keros in the Cyclades (Betancourt 2006, Georgakopoulou 2007, Georgakopoulou *et al.* 2011, pp. 123–124).

The study of three Early Bronze Age sites from Serifos, namely Kefala, Fournoi and Avessalos, is an example of successful dating of metallurgical activity, but as already mentioned this is not the norm. Dates for several kiln fragments have been established with the method of thermo-luminescence (TL) to the Early Bronze Age I and II periods in the first half of the 3rd millennium BC (Zacharias *et al.* 2006). Combined TL and optically-stimulated luminescence (OSL) dating of kiln fragments from Avessalos have provided dates ranging from the early 3rd to the late 1st millennia BC pointing to the diachronic exploitation of Serifos ores and use of the site (Zacharias *et al.* 2008). All the same, these dating techniques can only be applied to metallurgical ceramics. Nonetheless, an emphasis on the investigation of Bronze Age Aegean metallurgy is evident and at present no such work has being conducted on Iron Age sites in the Greek region.

Below, evidence of ancient copper mining related to metallurgical activities from sites all over the Greek mainland and the islands is presented as potential copper sources. Evidence from the Bronze and Iron Ages highlights the mineral wealth of Greece and the Aegean in relation to ancient copper-base metallurgical activities. Moreover, evidence of primary copper production and analyses of slag fragments from the vicinity of Thessaly is also discussed. Finally, this overview aims to list the available archaeological evidence for copper mining during the Greek antiquity, since absence of evidence for the exploitation of certain outcrops during the Early Iron Age does not necessarily have to be considered as evidence of absence.

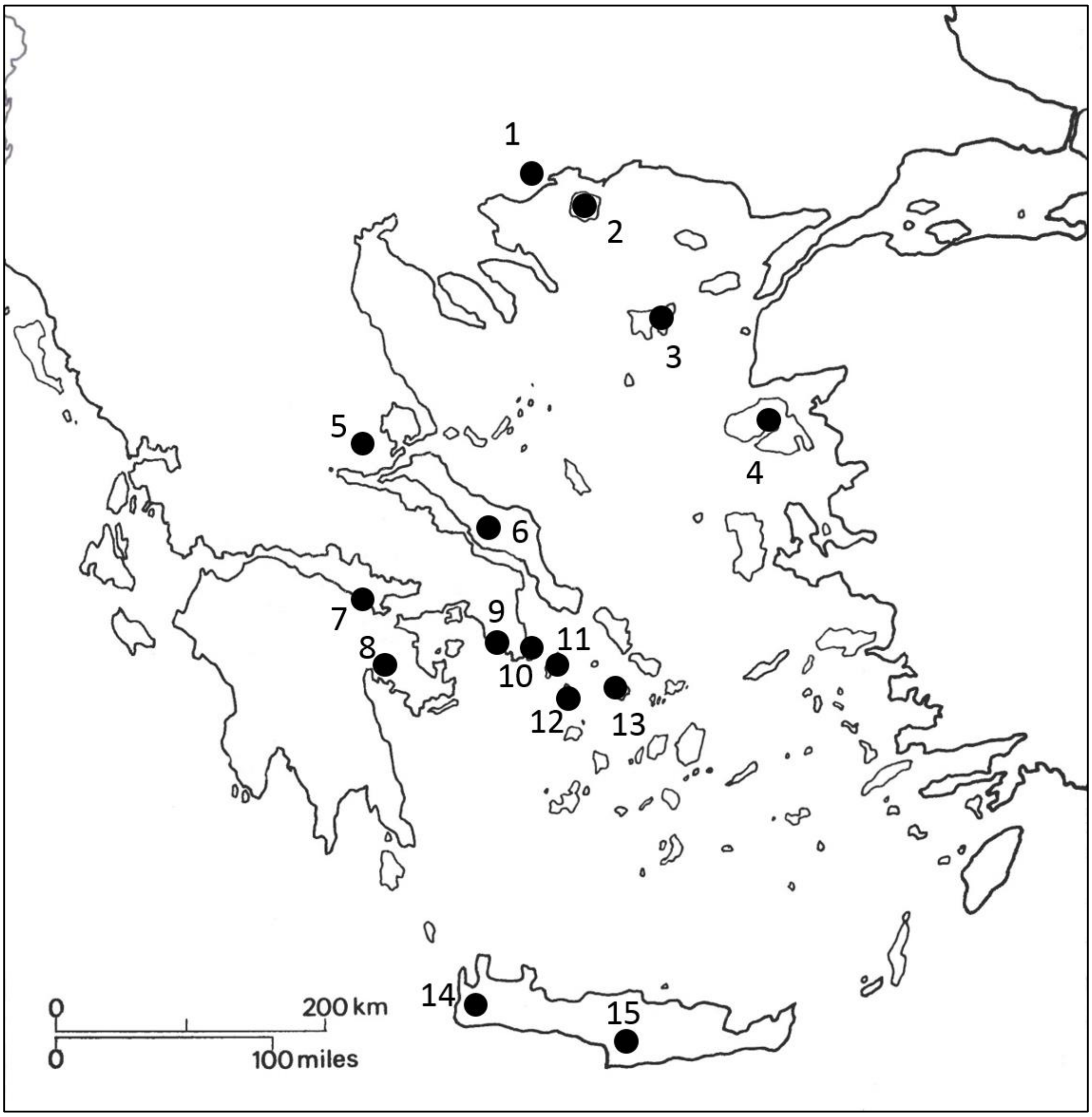
2.2.1.1 The Laurion district

The Laurion district is situated at the south-eastern tip of Attica; it covers an area of approximately 200 km^2 and includes a large polymetallic ore deposit, as well as a number of sites with traces of ancient mining and metallurgical activities such as Thorikos, Agrileza, Kampariza, Bertseko valley, Plaka, Soureza, and Sounion (Konophagos 1980, Gale and Stos-Gale 1982, Gale *et al.* 2009). Laurion deposits are rich in minerals containing lead, silver, iron, manganese, copper, zinc, and arsenic. Although the main metals extracted are lead and silver, copper is to be found in considerable amounts in a number of sites such as those of Plaka, Kamariza and Sounion. Evidence for the exploitation of copper rich minerals in Laurion recovered from the island of Kea in the western Cyclades and Raphina in Attica date back to the 3rd millennium BC, whereas there is evidence to suggest that Laurion was an important source of copper for the whole Greek Bronze Age (Gale and Stos-Gale 1982, Gale *et al.* 2009, pp. 158–161). Evidence from Alepotrypa cave in the Peloponnese, namely two pieces of Laurion (as suggested by lead isotope data) silver jewellery found together with a copper axe, point to the possible extraction of Laurion copper even as early as the Late Neolithic (Gale and Stos-Gale 2008) [recently the early dating of these two silver objects has been questioned and a much later date, possibly the Hellenistic period, has been suggested (Y. Bassiakos, pers. com)]. Finally, Laurion deposits were already well known in antiquity and are mentioned by ancient authors such as Herodotus, Thucydides and Pliny, and mining activity took place until modern times.

Copper in Laurion

In the Laurion district, copper is found both in oxidized and sulphidic deposits, of which the sites of Kamariza and Sounion are particularly rich. According to Gale and Stos-Gale (1982) ore bodies with up to 6-12% copper have been reported at the end of the 19th century (Phillips and Louis 1896), whereas in the mid-twentieth century Marinos and Petrascheck (1956) reported oxidized and sulphidic ores with a copper content of 3-6%. Oxidized ores often contain arsenic in levels high enough to account for the accidental production of arsenical copper during the Bronze Age (Marinos and Petrascheck 1956, Gale and Stos-Gale 1982, p. 18, Gale *et al.* 2009, p. 158).

Most evidence of Early Iron Age activity at the district has been lost due to modern exploitation. However, litharge recovered from Protogeometric strata suggests that metallurgical activities and silver refining, in particular, took place on site at least during the 9th century BC (Hopper 1968, pp. 293–4, 1979). Even though the exploitation of copper ores for this period has still to be confirmed (Gale *et al.* 2009), it is reasonable to argue that Laurion copper must have been exploited during several periods of Greek antiquity as copper extraction could have potentially happened in the Iron Age along with the lead and silver mining. Furthermore, Gale and Stos-Gale (1982, 1986) have argued that Laurion was one of the main sources of copper for the Greek Bronze Age and even more important source than Cyprus, particularly for the period preceding the Late Bronze Age.



1	Paggaion	6	Euboea	11	Kea
2	Thasos	7	Sounion	12	Kythnos
3	Limnos	8	Isthmia	13	Serifos
4	Lesvos	9	Argolid	14	Chrysocamino
5	Mt Othrys	10	Lavrion	15	Mesara

Figure 2.1. Copper ore sources in the Greek mainland, Crete and the Aegean with evidence of exploitation during different periods of antiquity (see also Kassianidou and Knapp 2005, p. 219, fig. 9.1)

2.2.1.2 Mainland Greece

Ancient mining activities have been reported from central and northern Greece and the Peloponnese (Papastamataki 1994). Mount Othrys which lies between Phthiotis and Pelasgia in southeast Thessaly is particularly rich in copper minerals, and both oxidized and sulphidic ores have been exploited in antiquity (Papastamataki *et al.* 1992, pp. 95–96). As suggested by several slag heaps found scattered in the region, extracted ores primarily include chalcopyrite, whereas some metallurgical activity confined to the oxidized zone has been related to the extraction of malachite and azurite (Papastamataki 1994, pp. 374–375, Papastamataki *et al.* 1994, p. 246). Slag heaps in Pelasgia have been estimated to be between 50,000 and 150,000 m^3 (Papastamataki and Dimitriou 1987, p. 566, Papastamataki *et al.* 1992, p. 208). Despite the apparent lack of accuracy and agreement in these estimations, the presence of significant amounts of slag and the importance of Pelasgia as a copper production site is firmly evidenced. Metallurgical evidence from the Phthiotis region including slag heaps and furnace fragments, ancient galleries, as well as traces of open air mining, eight mining shafts and two mining galleries of 124 and 191 m length, has been located at several sites such as Limogardi, Makrolivadi, Melitea (Aravitsi), Neochorio, Kastro Pelagia, and Archani (Papastamataki and Dimitriou 1987, Papastamataki *et al.* 1992, p. 243, Tizzoni *et al.* 2008).

Mining and smelting activity in Pelasgia and Phthiotis have been dated to the Hellenistic period in the 4th and 3rd centuries BC on the basis of Hellenistic pottery fragments recovered from Shaft 1 in Mount Othrys and in association with several slag heaps in both regions (Papastamataki *et al.* 1992, Papastamataki 1994, Tizzoni *et al.* 2008). Even though there is evidence to suggest earlier metallurgical activity possibly during the transition from the Bronze to the Iron Age in the 11th century BC, this is presently rather inconclusive (Papastamataki 1994, p. 376, Papastamataki *et al.* 1994, p. 248). It has been argued that the metallurgical centres of Phthiotis have not been in use simultaneously, but in different periods of Greek antiquity most probably covering the large time span from the Bronze Age to the Byzantine period (Papastamataki *et al.* 1992, p. 106, 1994).

Analysis of slag fragments from the region has produced a series of useful but at the same time contradicting results on the possible outcome of the metallurgical activities. Thus, Papadimitriou *et al.* (1992, p. 209) during their analysis of slags from Larisa Kremaste in Pelasgia have found three types of slag that differ essentially in their iron and silica contents. The three slag types are described as black glassy, dark grey crystallized, and ferruginous brown inhomogeneous. They have been interpreted as the possible result of either the treatment of different types of ores over one or more periods, or successive treatments of the same ore body, e.g. smelting followed by refining. Operating temperatures for the three slag types vary between 1100 and 1350˚C. It has been, finally, argued that during smelting at Pelasgia no fluxes were used and that good quality copper was produced (Papadimitriou *et al.* 1992, pp. 214–216). On the contrary, Papastamataki et al. (1992, 1994) and Tizzoni et al. (2008) have argued that slags from Phthiotis are by-products of primary smelting not followed by further refining processes that would have produced unrefined copper rich in iron. Additionally, Tizzoni et al. (2008, p. 544) note that slag analysis provided no evidence for further refining since a quite efficient reduction process was succeeded during primary smelting as indicated by the good fluidity and the low copper content of the slags from Phthiotis. Furthermore, scarcity of sulphide remnants in the slag and the low number of iron-rich slag fragments point to the processing of mainly oxidized ores. Finally, for these operations small size furnaces with a diameter of approximately 25 cm would have been used, whereas the recovery of high silica, glassy slag fragments suggests a strong interaction between the furnace walls and the charge (Tizzoni *et al.* 2008, pp. 541, 544).

Copper deposits

Just north of Mount Othrys, in the Pelasgia region, small copper outcrops have been located on the Chalkodonio Hill just a few kilometres from the site of ancient Pherae (Markos Vaxevanopoulos pers. com.), but at the moment neither the dating of their use or, in fact, their exploitation itself during antiquity can be addressed. In northern Greece, copper ore deposits at the Pangaeo Mountain associated with large quantities of arsenic bearing slags and speiss have been found in the area around Nikisiani, near Kavala, where activity has been dated from the Hellenistic to the Byzantine period in the 15th century AD (Papastamataki 1994). Traces of mining and metallurgical activities from northern Greece have also been found in Chalcidice, and the islands of Thasos and Samothrace, and in Sikyon and Argolis in northern Peloponnese (Voreadis 1954, Forbes 1964, Papastamataki 1994, p. 372, Papastamataki *et al.* 1994). Unfortunately, slag analysis from northern Greece or the Peloponnese is not at present available.

2.2.1.3 The Aegean islands and Crete

The Cycladic islands in the Aegean are particularly rich in copper, lead and silver mineralisations which have been exploited from the Bronze Age onwards. Copper ore deposits have been found in Serifos, Kythnos, Delos and possibly Kea (Mangou and Ioannou 1997, p. 64, Bassiakos and Philaniotou 2007, Georgakopoulou *et al.* 2011, pp. 138–139). Lead ores are widely known in the Cyclades such as from the islands of Melos, Kimolos, Antiparos, Thera, Anafi, Serifos, Mykonos, Kea, and Sifnos (Kordellas 1902, Renfrew 1967, p. 4, Mangou and Ioannou 1997, 1998, p. 93). Activity at Kea is dated both during the prehistoric and historic times (Papastamataki 1994, p. 376), whereas Serifos is well known for its metallurgical activity of not only copper, but also silver and lead from the Early Bronze Age, as well as for its iron deposits which have been exploited until quite recently in the mid-20th century AD (Georgakopoulou *et al.* 2011).

Elsewhere in the Aegean, copper mineralisations have been detected in Lesvos and Crete (Stos-Gale 1992, Papastamataki 1994, p. 372). Interestingly, even though scholars typically agree on the existence of copper mines in Crete these have not yet been located (Muhly 2008, p. 35, Tzachili 2008). Several copper mineralisations found on the island have been considered rather poor in relation to other sources in the Greek region such as the Laurion District, whereas no hard evidence for their exploitation has yet been recovered (Gale and Stos-Gale 1986, pp. 95–6). Lead isotope analysis for provenancing a group of Bronze Age copper oxhide ingots from Agia Triada has excluded Cypriot or Sardinian sources, while Anatolian sources have been suggested as possible candidates. So far, the exploitation of local ores including the mineralisations at Sklavopoulou and Chrysostomos has been largely ruled out (Gale and Stos-Gale 1986, pp. 96–99, Stos-Gale and Gale 2006) and oxide copper ore smelted at the Early Minoan site of Chrysocamino has been considered an import since the surrounding area is essentially mineral free (Betancourt *et al.* 1999, p. 352). Whether these copper minerals smelted at Chrysocamino were of Cretan or foreign origin is still a matter of open discussion as transportation of oxide ores by sea through a Cycladic connection have been suggested (Gale 1990, Stos-Gale and Gale 2006, p. 313). Finally, comparison of the Cretan mineralisations with the vast Laurion deposits does them little justice, whereas they could have possibly been a sufficient resource for prehistoric and protohistoric standards.

2.2.1.4 Cyprus

Additionally to copper ore sources in Greece and the Aegean, the renowned copper deposits of Cyprus cannot be excluded from the discussion of copper supply in the Mediterranean due to their large size and the active trading activity of Cypriot communities. Cypriot ores have to always be included in the list of possible copper sources used following the 12th century BC and during the formative years of the Greek Iron Age (Zaccagnini 1990, pp. 496, 499, Muhly 1998, p. 323). Cypriot exports of copper in the Aegean took off in the years following 1200 BC on the basis of a well-established trade and exchange network that could have possibly included the whole width of the Mediterranean as, for example, indicated by the cargo of the Uluburun shipwreck and copper oxhide ingots of Cypriot copper found in Sardinia (Gale and Stos-Gale 1986, Pulak 1998, 2001, Muhly 2008, Stos-Gale and Gale 2010, p. 391). Despite that this trading activity flourished during the Late Bronze Age and it seems to have declined in the beginning of the Iron Age, this alone does not straightforwardly point to the paucity of any activity in the succeeding period. Circulation of commodities in the eastern Mediterranean at the beginning of the 1st millennium BC could have still taken place in a different mode or in smaller scale as suggested by imports present at contemporary Lefkandi including bronze jugs from Egypt, cylinder seals from north Syria, Cypriot and Phoenician vases, as well as Greek pottery found in the Phoenician coast such as in Tyre already from the 10th century BC (Popham *et al.* 1980, Waldbaum 1994, p. 54, Popham 1995, Popham and Lemos 1995, Carter 1998, Lemos 2001). Even though if some of the imported finds are indeed heirlooms, the active relationship between Greece and the East at the break of the 1st millennium BC can hardly be denied.

2.3 The problem of ancient tin

Tin bears certain particularities that render it a special case amongst the rest of the metals used during antiquity from the Bronze Age onwards, making it one of the most debated subjects in the history of archaeometallurgical research of the Old World. Several monographs and conference sessions have been dedicated to this topic (e.g. Muhly 1976, Franklin *et al.* 1978, Penhallurick 1986, Giumlia-Mair and Lo Schiavo 2003), whereas active discussions have taken place in scientific journals such as these of 1991-2 in the *Journal of Mediterranean Archaeology* (Hall and Steadman 1991, Pernicka *et al.* 1992, Willies 1992, Yener and Goodway 1992) and of 1993 in the *American Journal of Archaeology* (Muhly 1993, Yener and Vandiver 1993) on the presence or not of tin sources in Anatolia. In addition, published articles in popular magazines too suggest that the interest on ancient tin extends to the public at large (Bass 1991, Jobe 1992).

Unlike other metals widely used in antiquity such as copper or iron, tin comes with a quite limited number of geological occurrences worldwide (for a review of available tin sources see Appendix V). Nonetheless, it has always been available in most metal-using communities including Greece starting with the Early Bronze Age, while recent evidence points to its use in the Balkans as early as the 5th millennium BC (Radivojević *et al.* 2013, 2014). Its provenance and the patterns of its supply in the tin-free regions through cultural networks of trade and exchange have long been among the main concerns of the archaeological research in order to interpret economic, technological and social aspects of past societies. The state in which tin was transported, i.e. in its mineral or metal state (ingots), the cultural contacts that its trade fostered, and the way the latter changed in the context of broader socio-political circumstances have been and still are a matter of scholarly interest and a long list of publication has presented often controversial evidence (e.g. Budd *et al.* 1995, Begemann *et al.* 1999, Yi *et al.* 1999, Haustein *et al.* 2010, Balliana *et al.* 2013, Pernicka 2014a). In the context of this active and vigorous discussion over tin use and supply a long list of publications has been dedicated to the specific topic presenting often controversial evidence for the existence of tin sources and/or their exploitation during certain periods in antiquity.

Finally, archaeometallurgical studies have mostly focused on the early use of tin rather than historical periods (e.g. Weeks 1999, Radivojević *et al.* 2013, Lehner and Yener 2014). Similarly, Greek and Aegean studies have dealt extensively with Bronze Age metallurgy rather than the Iron Age even though during the latter tin bronze was established as the main copper alloy for the production of metals in an unprecedented scale. This is to be also attributed to several limitations of both the archaeological record itself, as well as the potentials of its analytical investigation. For instance, tin ingots as found on Late Bronze Age shipwrecks for the period between 1200 and 500 BC (Northover 1989a, Pulak 2000) are absent from the Mediterranean archaeological record since no shipwrecks with similar cargo have yet been recovered (Muhly 1998, pp. 319–320). Likewise, no other evidence for the trade of tin either in its oxide or metallic form has been recovered, whereas evidence of tin mining and smelting is remarkably poor and often difficult to date. In the course of Greek archaeology, this absence of evidence for the Iron Age tin supply goes in hand with the concept of a 'Dark Age' which was presumably the result of social unrest caused by the collapse of the Mycenaean palace system (see also discussion below Chapter 2.3.1). Moreover, tin is mostly found as an alloying element dissolved in copper which introduces further limitations for its archaeometric investigation as tin isotope studies for provenancing ancient tin sources are a matter of ongoing investigation (Pernicka 2014a) (for a discussion of the potentials of tin isotope analysis in archaeology see Appendix V).

2.3.1. Tin sources in the Old World

Since the Early Bronze Age tin has been an integral aspect of past societies including these of the eastern Mediterranean. Yet attributing its supply to specific ore sources has never been a straightforward task. In the case of the Greek mainland and the Aegean, in particular, there are a number of possible tin deposits that could have supplied local metalworkers all of which would have involved not only long distance trade and transportation, but also well-established supply-and-demand and gift exchange networks in which the surplus of tin of tin-producing communities would be exchanged for other goods. Tin sources, as well as traces of early tin mining in the Old World have been located around Europe, Anatolia, western Asia and northern Africa (a number of publications provide a detailed account of these deposits, e.g. for quite detailed list of tin occurrences see McGeehan-Liritzis and Taylor 1987). A theory of tin belts has been proposed for Eurasia in order to explain the occurrence of tin deposits in seemingly random areas (Schuiling 1967). However, the early date of this effort does not take into consideration several significant tin deposits such as those in the Arabian Peninsula or Iran (Figure 2.2). The aforementioned debate over the supply of tin and the different periods of exploitation of known sources, further extends to the presence or not in certain areas of the cassiterite deposits themselves too (the chief ore of tin), i.e. tin outcrops have been reported but it is not possible to locate, whereas in other cases tin deposits have been assumed to be present on the basis of solely archaeological evidence and whose discovery, if they exist indeed, is still pending.

Ancient tin sources were of strategic importance and must have provided a certain degree of power and control to the local communities over the tin-free ones since tin was a critically valuable commodity of economic, technological and cultural significance from the Early and Middle Bronze Age onwards (Stech and Pigott 1986, Yener and Vandiver 1993). Tin sources have been found in just a few localities as opposed to the abundant copper or iron ores in the Earth's crust but they are present in several areas surrounding the Mediterranean such as in Europe, western Asia, Anatolia and northern Africa. This makes it rather difficult to pinpoint the supply of tin metal in the eastern Mediterranean from a single source over the different periods of antiquity (De Ryck *et al.* 2005, p. 262). Accordingly, tracing ancient tin metal used in Greece and the Aegean where tin bronze was extensively used particularly from the Middle Bronze Age onwards back to its origin still remains in the sphere of speculations (Mangou and Ioannou 1997, p. 64, 1998, p. 93).

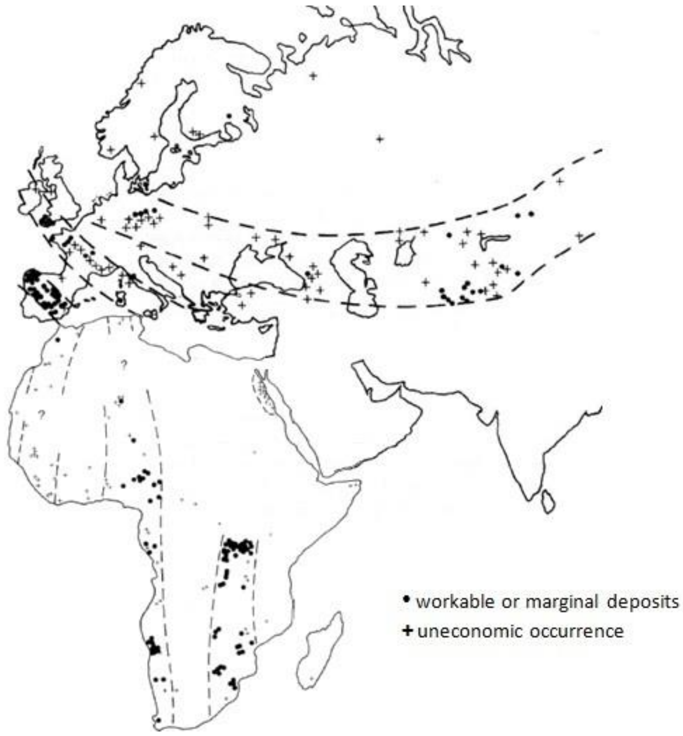


Figure 2.2. Tin belts in Europe, western Asia and Africa (after Schuiling 1967; de Jesus 1978, fig.3-4)

Literary evidence from cuneiform texts dating to the 3rd and 2nd millennia BC refer to the trade of tin in Asia via caravans with an east-west direction, pointing to the east for a possible mineral source for Mesopotamia, Anatolia, and even the eastern Mediterranean (Muhly 1985, Weeks 1999, p. 51). An implication of these texts in the course of archaeological research has been that despite that the original source(s) of tin involved in this network have not been located, on the basis of underlying assumptions there does exist a tendency to look for a single tin source (Muhly 1973a, Yener and Vandiver 1993, p. 212, Weeks 1999, p. 61). For instance, with new data brought to light extended discussions have taken place for as to which was the tin supply of Bronze Age Mesopotamia between either the east, e.g. Afghanistan, Iran or even further east in India, or the west, e.g. Anatolia and the

Taurus Mountains (Weeks 1999, pp. 50–51, De Ryck *et al.* 2005, p. 267). However, and as mentioned above even for such early periods proposing a single source of tin is merely based on an assumption. The possibility of multiple sources of tin supplying one region should be taken into account certainly for the Iron Age on the basis of the long-term operation of different trade networks, but most likely for earlier periods and the Bronze Age as well (Birmingham 1961, Pickles 1988, p. 11, Zaccagnini 1990, p. 499, De Ryck *et al.* 2005, p. 262, fig. 1). A brief account of the main tin sources in the Old World and of some evidence for their early exploitation follows with the intent to highlight potential tin sources that could have been used in the eastern Mediterranean during the Early Iron Age.

2.3.1.1 Europe and the Mediterranean

Most scholars agree on the existence and exploitation during prehistory of the European tin sources. Primary lodes and alluvial tin occur in Cornwall and Devon in southern England, central Europe such as the Massif Central and the Armorican Massif in France, and the Erzgebirge tin district between Saxony and Bohemia, i.e. modern east Germany and Czechoslovakia, as well as on the Iberian Peninsula, Tuscany and Sardinia in Italy (Taylor 1983, Muhly 1985, McGeehan-Liritzis and Taylor 1987). Additional tin sources with possible ancient exploitation have also been reported in Yugoslavia (McGeehan-Liritzis and Taylor 1987). Traces of ancient mining have been found in most of these sites. Meanwhile, the possibility of the exploitation of alluvial tin in the form of black pebbles which would not leave any traces must also be taken into consideration from the early stages of tin production.

Activity at the British tin mine in Cornwall dates well back into the Early Bronze Age in the 3rd millennium BC and it must have been a significant source for the European continent at least for certain periods of antiquity despite the additional continental tin sources (McKerrell 1978, p. 7, Needham *et al.* 1989, p. 393). Tin mineralisations at Monte Valerio in Tuscany have provided evidence of exploitation by the Etruscans in the Early Iron Age at around 800 BC. However, it has been suggested that the supply of the rest of the Mediterranean with Etrurian tin is doubtful due to the rather small size of these deposits (Benvenuti *et al.* 2003). Tin around Italy is also found on the islands of Elba where it is associated with ferrous minerals as in the case of the Taurus Mountains (see below), as well as in southern Sardinia (Boni and Ippolito 1976, Valera and Valera 2003). Mycenaean presence in Sardinia as indicated by imported pottery finds is evidenced at least from 1400 BC until 1050 BC would, for example, suggest the supply of Sardinian tin during the Late Bronze Age in Greece and the Aegean (Bernardini 2010, p. 13).

Relative abundance of tin is also found at the west part of the Iberian Peninsula in Spain and Portugal, whereas the tin fields of Lusitania and Galicia are also known from literary sources such as Pliny and Strabo (McGeehan-Liritzis and Taylor 1987, p. 288, Muhly 1998). The city of Tartessos in south-west

Spain has been said to be a significant Phoenician trading post for the Early Iron Age through which tin was supplied in the rest of the Mediterranean (e.g. Aubet Semmler 2002, pp. 225–226, contra Muhly 1998). In Erzgebirge, even though the presence of tin mineralisations is beyond dispute, its exploitation during the early phases of the Bronze Age has been doubted due to the nature of the deposits (Muhly 1973b, 1985). Nonetheless, this tin district must have been exploited at least during the Iron Age during which fire-setting could have taken place to facilitate tin extraction, whereas some alluvial tin could have possibly been present (Taylor 1983).

When it comes to mainland Greece and the Aegean absence of tin deposits has been generally accepted since the local geology is not suitable for the formation of cassiterite (McGeehan-Liritzis and Gale 1988, p. 289). However, there has still been suggested the possibility of small alluvial tin deposits exhausted already in antiquity, of which no trace is left today (Renfrew 1967, p. 13). Furthermore, geological surveys conducted in the 1980s in the broader Aegean region provided evidence of small outcrops of tin-bearing minerals that could have been exploited in a context of small scale tin and bronze production (Skarpelis 2003). A possible tin source has been reported in Kirrha in Phocis, modern Itea, by Davies (1929). Even though this tin source and its ancient exploitation is considered a certainty by Wainwright (1944, p. 59) who mentions that in Kirrha *'the mining of tin in open casts was for long the chief industry'* during the second half of the 2nd millennium BC, no evidence of such source was found by Benton when she visited the site (1964, p. 138) whose conclusion has not been revisited since. Finally, Cyprus despite its mineral wealth it is essentially tin-free, whereas tin was only introduced on the island in the form of bronze artefacts more or less simultaneously with the rest of the Greek world at the transition between the Early and Middle Cypriot periods, i.e. the equivalent of Early to Middle Bronze Age Aegean, in the 3rd millennium BC (Muhly 1999, p. 17).

2.3.1.2 Anatolia, western Asia and northern Africa

For the most of the twentieth century the absence of a tin source in Anatolia, a region where tin bronze artefacts appear very early in the archaeological record from the late 4th-early 3rd millennium BC and certainly earlier than other surrounding areas (Yener and Vandiver 1993, p. 208), has been striking. Evidence for a tin source exploited at least as early as the Bronze Age was presented only in the late 1980s with the work of Yener *et al.* (Yener and Özbal 1987, Yener *et al.* 1989, Yener and Vandiver 1993), and until then the import of tin blocks in the region for the production of bronze was assumed (Çukur and Kunç 1989, p. 230). At Kestel mine and the nearby site of Göltepe in the Taurus Mountains, located in south central Anatolia and some 80 km north form the coastal city of Tarsus, early traces of tin ore extraction have been found. Although in the following years the validity of this Anatolian tin source has been criticized (Muhly 1993), examination of both the geology of the Kestel mine, associated metal artefacts, stone tools and crucibles from Göltepe has proven that tin mining and smelting took place in the Taurus Mountains possibly along with gold winning for the whole 3rd millennium BC (Earl and Özbal 1996).

Cassiterite is found at the Kestel mine in a matrix of hematite resulting in a not particularly rich source even for ancient standards but a multi-step process taking advantage of the different magnetic properties of iron and tin oxides as shown by Laughlin and Todd (2000) could have resulted in the concentration of significant amounts of tin from the Early Bronze Age onwards. All the same, poor tin ore found today at the mine could always be the result of the extensive mining of the more tin-rich veins and it looks as if Kestel mine was in operation until it was worked out (Earl and Özbal 1996, p. 296).

On the basis of early tin bronze finds from the Troad in north-east Anatolia and in the north Aegean islands, as well as a predominance of tin bronze during the Early Bronze Age (Gale *et al.* 1985, p. 157) it has been suggested that a tin source must have existed in the broader area, possibly including the Pontic region, which must have contributed in promoting the early local bronze technology (Renfrew 1967, p. 13, de Jesus 1978, p. 38, Muhly 1993, p. 241). Even though, the validity of this suggestion has been challenged early on (Wainwright 1944, p. 59), some cassiterite has been found near Bursa in north-west Anatolia (Kaplan 1983, Yakar 1984, p. 80). In any case the possibility for the presence of additional small cassiterite outcrops already exhausted in antiquity in the Troad and central Anatolia still remains.

In western Asia several tin sources have been discovered which would have sustained local bronze production, but they also played an important role in the tin supply of Mesopotamia, Anatolia and the eastern Mediterranean during antiquity (Stech and Pigott 1986, De Ryck *et al.* 2005). Evidence of ancient mining activities has been found at tin deposits in several areas in Afghanistan, whereas tin was possibly extracted in Iran as well even though the latter is based more on the geological environment rather than archaeological evidence (De Ryck *et al.* 2005, p. 262). Iran as a potential tin source of eastern Mediterranean and the Near East is also indicated in the literary tradition of the Iron Age such as Strabo even though only minor tin occurrences have yet been located there (de Jesus 1978, Weeks 1999, p. 60). Although suitable geological conditions for the occurrence of tin exist in several parts of Iran, primary and placer cassiterite outcrops have been reported only at the far east of the country (Weeks 1999, 50). Finally, Middle Bronze Age tin mining has been also reported in Uzbekistan by the Aral Sea (Kuzmina 1966, Masson and Sariandie 1972, p. 128, Crawford 2004, p. 243).

Tin-bearing granites have also been located in the north-east Africa and the areas surrounding the Red Sea such as in Egypt, the Eastern Desert and on the sixth cataract of the Nile in Sudan in Africa, as well as Saudi Arabia and Yemen on the Arabian Peninsula (Wertime 1978a, p. 2, Du Bray 1985, Muhly 1993, Kamilli and Criss 1996, Weeks 1999). Tin at the Eastern Desert occurs both as granite-hosted and alluvial black tin pebbles. These tin deposits have been found particularly rich as opposed to the Taurus Mountain veins, whereas this could point to the limited exploitation of the former during antiquity (Muhly 1993, pp. 239, 244). The early exploitation of both the Eastern Desert and Arabian Peninsula deposits is doubtful and no traces of their systematic exploitation prior to 2000 BC have been found.

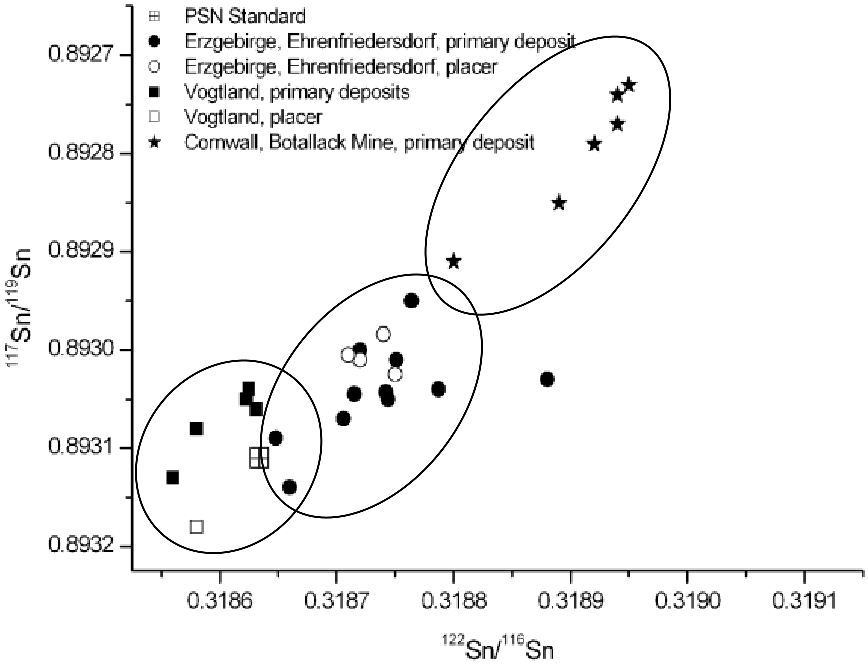


Figure 2.3. Scatter plot showing ratios of tin isotopes for the deposits in the Erzgebirge and Cornwall (after Haustein et al. 2010, fig. 3)

2.3.1.3 Tin isotope studies and the potentials

The possibility of isotopic studies for tin provenancing has long been discussed as a potential (Muhly 1985, p. 290), whereas the first results of such analytical methods have been presented from the late 1990s onwards (Gale 1997). Even though, tin is less useful in isotope tracing, and the accuracy and interpretations of these data may differ (Begemann *et al.* 1999, p. 279, Yi *et al.* 1999, p. 285), recent research on tin isotopes does form a step forward in the investigation of ancient tin supply. Pilot studies for the provenance of tin from archaeological contexts include the application of different analytical techniques on cassiterite, tin metal and intermetallic phases. For instance, neutron activation analysis (NAA) of cassiterite showed that it can potentially be traced back to its geological source (Rapp *et al.* 1999), whereas analysis by proton induced X-ray emission (PIXE) of intermetallic copper- and iron-tin phases in unrefined tin metal has been found to provide trace element fingerprints characteristic enough to distinguish between different tin sources (Northover and Gillis 1999). These recent studies have admittedly assisted to a degree in clearing up the problem of tin and questions regarding the relation between the elemental signatures of cassiterite and its host granite (Weeks 1999, p. 60), whereas further issues do of course remain (Begemann *et al.* 1999).

Finally, Haustein et al. (2010) have recently produced tin isotope data of primary tin deposits in the Erzgebirge district and Cornwall in comparison with the associated placers and have argued that different tin sources do have characteristic tin isotope fingerprints that can be measured and which are significantly homogenous (Figure 2.3). Further work on the field could potentially result in resolving the 'problem of ancient tin' and its sources which has been described as *'a vexing* problem', *'the knottiest of the problems'* and *'perhaps the greatest mystery of all'* (Wertime 1978a, p. 1, 1978b, p. viii, McGeehan-Liritzis and Taylor 1987, p. 287).

2.3.2 The tin shortage theory and its implications

'A tail of *true believers* and *radical skeptics'*

(Muhly 1998)

The distribution of ancient tin has preoccupied much of the archaeological community in relation to the Bronze to Iron Age transition and the introduction of iron technology in the eastern Mediterranean and Near East. For the latter several hypotheses have been suggested including a) the energy/fuel shortage according to which less fuel was needed for iron production as opposed to bronze, b) the advances of iron technology itself, i.e. the introduction of carburization (steel) and quenching, which increased its hardness, c) its spread by the intervention of foreign groups such as the Hittites or the Dorians (for an overview see Pickles 1988, pp. 11-13). Nevertheless, the most discussed of these theories is that of tin shortage first formulated by Snodgrass in the early 1970s (1971, pp. 237–239).

The so-called *tin/bronze shortage theory* was a rather controversial argument regarding the supply of tin in the aftermath of the Late Bronze Age. Snodgrass's starting point was the concept of a general socio-political breakdown followed by a deep recession in Greece and the Aegean which must have resulted in paucity of contacts with the East and the abandonment of Mycenaean trade and exchange networks. Such theory stems from the notion of a *Dark Age* of Greek antiquity during which communities were allegedly introvert and backward, and which was caused by Late Bronze Age catastrophic events (see also Chapter 1.1.1). This theory gained some consensus among scholars particularly in the 1970s and 1980s (Desborough 1972, p. 314, Waldbaum 1978, Strange 1987, p. 7). However, this was largely based on assumptions and on the interpretation of remarkably limited actual archaeological evidence. Even at the point of the bronze shortage theory's formulation, Snodgrass himself acknowledged that the body of evidence is limited, whereas he mainly relied on evidence from Attica (Jones 1980, p. 458, Snodgrass 2000, p. 238). Often scholars have been predisposed in favour of the bronze shortage theory and have used this hypothesis in order to interpret the archaeological record, instead of employing the latter to test this hypothesis, thus leading to a circular argument. This is well illustrated in the remark that *'there is no reason what so ever to suspect that the bronze technology should have been abandoned [in favour of iron technology] unless we suppose that bronze had become a scarcity in itself'* (Strange 1987, p. 13). As the above admits there is no direct evidence for a shortage of bronze in itself but it had to be *assumed* in order to account for the poor understanding of the conditions under which iron working was introduced. In addition, Similarly, bronze weapons found in Protogeometric contexts, i.e. the period of shortage, in central Greece and the Peloponnese have been found to be *'symptomatic'* and have been dated to earlier periods primarily on the basis of typological evidence and the macroscopic evaluation of their craftsmanship. It was again the hypothesis of tin shortage itself that dictated an earlier dating which otherwise would be unfounded. Thus, weapons from Delphi Olympia found in association with Protogeometric pottery have been considered heirlooms which *'very probably'* date to the late Mycenaean period, whereas a sword from a Geometric burial in Boeotia has been *'almost certainly'* considered of Mycenaean origin too (Snodgrass 2000, pp. 240–241).

Similarly, in order to justify the resume in bronze working in the periods following this assumed absence of tin, the presence of Near Eastern craftsmen in Geometric Greece who have allegedly re-introduced bronze technology has been suggested (Rolley *et al.* 1983). Papadimitriou (1992) taking on from Rolley et al. (1983) and Mangou et al. (1986) has suggested that the deterioration in alloy quality in Geometric bronzes supports the interruption of trading activity of mainland Greece with the traditional metallurgical centres of the East at the break of the 1st millennium BC, even though the Geometric period itself only begins in the 8th century BC when external contacts would have already been resumed even according to the tin shortage theory (Snodgrass 1971, p. 237, Morris 1989, p. 508). Nonetheless, the contemporary archaeological record points to contacts between Greece and the East as indicated by the funerary record and imports of Early Greece (Hoffman 1997, Lemos 2003). In addition, the Near Eastern contacts are described in subsequent periods and in Classical texts which discuss the social position of *metics*, i.e. foreigners living in Athens (Whitehead 1977). However, absence of written sources for the Early Iron Age alone is not sufficient to exclude cultural contacts of various natures and different scale taking place in the years prior to the 8th century BC that could possibly supply Greece with a tin. Nevertheless, a change in metal quality could have been the result of smaller scale production and exploitation of different ores and not necessarily of the paucity of long-distance contacts (Muhly 1998).

Even though a change in the patterns of the archaeological record of metal objects does occur for the period of approximately 1050-950 BC in Greece such as in grave offerings, this need not be interpreted in the narrow context of resources availability, but rather as the result of the development of existing social structures which left a distinct cultural imprint (Morris 1989). Changes in the way people acquired, traded and produced metals and alloys should not straightforwardly be perceived as the paucity of metals trade and tin in particular (Kayafa 2006, p. 227). In addition, archaeological evidence and analytical data generated from the 1980s onwards point to the continuity of local traditions at the break of the 1st millennium BC proving a 'falsely imposed' Dark Age (Rapp *et al.* 1978, Muhly 1985, 1998, p. 323, Pickles 1988, Zaccagnini 1990, p. 497). The evidence from Lefkandi is one such characteristic example as its analysis suggested that all base metals were available to local metalsmiths during the Early, Middle, and Late Protogeometric periods. Variability in the tin contents from low to high amounts point to a lack of concern that would not fit the case of a scarce resource (Jones 1980, pp. 457–458). Alternatively, if only bronze recycling took place the tin content would have been consistently low since substantial loss of the original tin content would have occurred upon remelting operations (Budd *et al.* 1995, Gale 1997, p. 72). Nonetheless, metal reuse, recycling and mixing is indeed a very important aspect of ancient metal technologies as also discussed by recent studies (Bray and Pollard 2012), and it has to be considered as an integral part of metal production and alloying during antiquity.

Overall, the tin shortage theory has been employed in order to compensate for the rather poor understanding of a formative period of Greek antiquity at the beginning of the 1st millennium BC. Late Bronze/Early Iron Age Greek communities have been seen as passive elements adapting to externally imposed circumstances such as the paucity of tin supply or, in fact, the renewed interest in bronze working by non-Greek bronze smiths. Despite that at the moment it is generally accepted that a tin shortage has been based on the misinterpretation of the evidence or the lack of it, in a sense the debate is still ongoing. Since its formulation the tin shortage theory, if nothing else, has raised a vigorous scholarly debate which has produced a significant amount of work discussing its starting point, validity and correctness with numerous implications for the study of Early Iron Age Greece. Researchers involved in the study of early Greek copper-base production have been contributing for or against the shortage of tin and, thus, the Dark Age as if they almost felt obliged to.

2.4 Analysis of Early Iron Age copper-based artefacts from Greece

Despite the thousands of copper-based objects found in deposits from the Early Iron Age sanctuaries all over Greece and Asia Minor their technology has been remarkably understudied as reflected in the available published analytical data. Although an interest in the compositions of ancient metals has been expressed early on from the late 18th century (Klaproth 1798, Caley 1949, 1951, 1967), when it comes to early Greek bronzes publications are limited to a handful of papers published from the early 20th century onwards. In addition, the aforementioned publications differ in their scope and aim as their authors have different backgrounds, interests and starting points, and thus they explore different archaeological questions. Consequently, drawing a complete picture for the post-Mycenaean bronze technology is all but a straightforward task. The level of archaeological interpretation of these publications varies significantly from raw data presentation (Davies 1934) to attempts of understanding human interaction, and technological knowledge transfer (Rolley *et al.* 1983) or pinpointing changes in copper alloy composition over time (Craddock 1976) by using a variety of analytical techniques. These approaches come with different advantages and limitations which are discussed in detail below in an attempt to illustrate what has so far been argued for the Early Iron Age copper-based technology in Greece and the Aegean.

2.4.1 Published analytical data

Analyses of Early Iron Age Greek copper-based artefacts have been published throughout the 20th and into the 21st centuries despite that they are scarce. Thus, in the 1930s, Davies (1934) published analytical data of a number of Greek bronzes dating from the Bronze and Iron Ages. The assemblage consisted of solely surface finds recovered *'during his wanderings'* (Davies 1934, p. 131) including a group with Geometric artefacts from a refuse heap near the Argive Heraion, whereas other sites represented include the Samian Heraion, Asine in Argolid and Olympia. Davies' interest lay primarily in the attribution of metal objects to certain geological sources in an attempt to list some of the mines exploited during the Bronze and Iron Age in Greece and elsewhere. The material was classified according to chemical composition and compositional groups according to trace elements concentrations. This emphasis, as opposed to a typological, chronological or regional categorization, allowed Davies to put forward a diachronic perspective for the use of copper ores and alloying by early Greek smiths. Conclusions showed that in the Late Bronze and Early Iron Ages copper from several different ores has been used by the Greeks. Assuming that elements present in the ores are also present in the metal produced, Davies noted that a variety of local ores including those from Othrys in southeastern Thessaly, Kos, and Thasos, as well as non-Greek ores, such as from Italy and Cyprus and concluded that a variety of copper sources would have been used by the Greeks in the Late Bronze and Early Iron Ages (Davies 1934, p. 136). However, at the of Davies' published comparative material to further discuss and explore his suggestions was not available, while his methodology was not adequately accurate. Meanwhile, the investigation of the technological characteristics of this rather diverse assemblage evident was not in his immediate interest.

Furthermore, certain limitations apply in Davies' methodology as a rather simplistic link between the composition of ore bodies and metal objects was assumed (for a detailed discussion see Tylecote *et al.* 1977; Pernicka 1999). Although he acknowledges the possibility for the use of scrap metal in the production of copper alloys, he fails to consider other alternatives such as the simultaneous use of more than one ore sources in the melt, the possible effects of alloying, recycling and remelting of the objects in the minor and trace element compositions (Craddock 1976, p. 94) or the heterogeneity of ancient metals (Charles 1973, Craddock 1976, p. 97) and the corrosion effects on the metal compositions (Scott 1985, Fabrizi and Scott 1987, Robbiola, Blengino, *et al.* 1998, Robbiola, Pereira, *et al.* 1998, Ingo, De Caro, Riccucci, and Khosroff 2006). Additional issues occur as the analytical method or the instrument's accuracy and precision have not been discussed and also because it was mostly corrosion layers that it has been analysed during surface examination of the objects. Analytical totals ranging between 9% and 101% with an average of 70% (Davies 1934, p. 132) also suggest that the presence of corrosion products during analyses as the remaining percentage would most likely consist of oxygen, carbon and chloride, namely elements present in copper corrosion, while these are not reported by Davies. Finally, corrosion effects and decuprification of copper alloys would also explain the high amounts of iron and zinc, and the lower copper content for these objects (Robbiola, Pereira, *et al.* 1998).

Questions regarding changes of Greek copper alloys over time have also been put forward by Craddock, in a series of three papers in which he investigated changes in copper alloy composition from the Bronze Age to the Roman period in the 4th century AD (Craddock 1976, 1977, 1978). Craddock's approach overcomes some of the limitations of Davies analysis. For example, the sample is much larger with a total of 860 artefacts for all periods and better dated even if it is done *'within broad limits'* allowing for safer conclusions to be drawn, while, both chronological and typological groupings were discussed. Main aim of this work was to *'discern trends in metal composition'* and to describe the range and type of alloys used in antiquity and the degree of quality control exercised during their production (Craddock 1976, pp. 93–95).

Contrary to Davies, Craddock discussed the aforementioned limitations in tracing the finished objects back to specific copper sources. Nonetheless, Craddock still considered trace element analysis as a potential method for the provenancing of metal but admittedly in a rather critical way. He also focused on the investigation of metal impurities as a means to explore the smiths' skill in metal purification and how these changed over time (Craddock 1976, p.94). Some of his observations include the gradual introduction of tin bronze that replaced arsenical bronze, the co-occurrence (accidental or not) of tin and arsenic in the transition period from the Late Bronze to Iron Age, and the ability of smiths even as early as the Early Bronze Age to produce arsenical copper as a deliberate alloy and to exercise control over the finished objects' composition. For the Geometric period, in particular, he notes the extended use of tin bronze for pins, decorative objects and statuettes with means just below the optimum 10% tin bronze which was also the *par excellence* alloy used in early Greece (Papadimitriou 2001, p. 597), whereas greater variability in the lead content as opposed to the tin takes place. The use of scrap arsenical copper has been accounted for the presence of small amounts of arsenic at around 1% As.

At the time of Craddock's synthetic analytical work, two excavation reports published both qualitative and quantitative data on the composition of Early Iron Age Bronzes. Bronze objects from the sites of Nichoria in Messenia (Rapp *et al.* 1978) and Lefkandi in Euboea (Jones 1980) have been examined with various analytical techniques driven by different archaeological questions. While the Lefkandi report was meant to be a '*preliminary account of the results […] of a representative number of base metal* *objects'* with a primary concern to determine the nature of the copper-based alloys present and to spot any imports or distinct compositional groups (Jones 1980, p. 447), the investigation of Nichoria material addressed more prolific questions in regard to diachronic technological changes, the degree of specialization and sophistication of metallurgical processes, and the relation between chemical composition and the function of the finished objects (Rapp *et al.* 1978, p. 166). At Nichoria, this was also possible due to the long chronological sequence represented in the assemblage from the Middle Helladic period to the so-called Dark Age, whereas Lefkandi bronzes cover a norrower time span from the Submycenaean to the Subprotogeometric period [the latter corresponds to the proper Geometric period for mainland Greece due to the long tradition of Subprotogeometric pottery production in Euboea (Lemos 1996, Coldstream 2003)].

Table 2.1. Summary of the XRF analysis of 111 copper and copper-base alloy objects from the cemeteries of Toumba, Skoubris, and Palia Perivolia at Lefkandi, Euboea by Jones; values in wt% (after Jones 1980, 451-3)

	Zn	As	Fe	Cu	Sn	Pb
mean	0.0	0.0	2.8	84.4	7.9	5.1
max	2.0	0.5	30.0	100.0	20.0	30.0
min	0.0	0.0	0.0	20.0	0.0	0.0
1st quartile	0.0	0.0	0.0	82.0	4.3	0.0
median	0.0	0.0	0.0	91.0	6.4	0.0
3rd quartile	0.0	0.0	0.5	94.6	10.7	4.0

Non-destructive, surface analysis of metal artefacts for both Lefkandi and Nichoria reports was conducted by Jones using XRF with an Isoprobe which was an established method at the time (Catling and Jones 1976). This surface XRF analysis bore certain limitations that render its results qualitative or semi-quantitative at best due to surface corrosion phenomena and issues concerning the analytical instrument itself (Karydas 2007). For instance, detection limits of the XRF are reported to be as high as 1% for some elements such as lead and arsenic, whereas a detection limit of 0.5% for copper, tin, zinc and iron is still quite high. In addition, the standards used for both sets of analysis while satisfactory for low tin, lead and iron concentrations, they were unsuitable for tin and lead concentrations above 15% and 10% respectively (Rapp *et al.* 1978, p. 172, Jones 1980, p. 447). Estimation on the accuracy of the tin content showed a ±15% for objects with good state of preservation (A/B, surface characterization by Jones) and ±20% for more deteriorated surfaces (C/D). Overall, Nichoria results are more accurate owing to the fact the metal surfaces have been cleaned by corrosion products, whereas certain oxides may have still been preserved in what appeared to be a metallic surface (Rapp *et al.* 1978, p. 172). Meanwhile, analysis of the Lefkandi material was conducted on unscrapped corroded surfaces or objects that have already undergone conservation treatment during which a polyvinyl coating was applied over the cleaned metal surface (Jones 1980, p. 447) which would explain the high iron, lead and the elevated tin contents that are reported for Lefkandi bronzes (Table 2.1). The decuprification phenomenon (as also for Davies' analysis) could explain the low copper values for some of the objects. For instance, the fibula T 1.10 from the Toumba cemetery with 30% lead, 15% tin and over 30% iron reported (Jones 1980, p. 452) is definitely a corroded artefact and analytical results reflect the compositions of growth corrosion layers.

Despite the aforementioned limitations, both sets of analyses confirmed the presence of tin as an alloying element during the Early Iron Age, while objects of unalloyed copper were scarce. Average tin distribution was found at 8% and 13% Sn for Lefkandi and Nichoria respectively pointing to the addition of fresh tin as opposed to the mere recycling of Bronze Age material. Moreover, the addition of tin in the Nichoria sample in excess of 12% has been considered as proof of a valuable resource's waste since a 10% tin bronze would have achieved the maximum hardness and minimum brittleness, thus supporting further the availability of fresh tin (Rapp *et al.* 1978, p. 178). Nonetheless, if hardness was not sought after, but other properties such as the metal's colour or brightness, then the use of higher tin contents could be the result of a deliberate, culturally dictated choice (Orfanou and Rehren forthcoming). Finally, leaded tin bronzes occur more often in the Lefkandi assemblage with a mean of 5% Pb, whereas in Nichoria lead average does not exceed 1.5% and only one object contains more than 1% lead which is also rich in tin (object N 1335 with 16% Sn and 20% Pb), and excluding the object N 1335, lead mean falls immediately to 0.2% Pb.

In 2009, a more targeted analysis of material from the Toumba cemetery at Lefkandi was conducted (Orfanou and Rehren forthcoming, Orfanou 2009). This was to complement the previous analyses by Jones which provided a framework for further examination (Jones 1980, pp. 458–459, note 32). Nineteen copper-based objects were chosen for invasive compositional and metallographic analysis. The samples' morphological features were examined with an optical reflected microscope which pointed to different metalworking techniques used for the manufacture of the examined objects as traces of both casting, hammering and annealing, namely repeated cold and hot working, were detected. Quantitative analysis was conducted with scanning electron microscopy with an attached energy dispersive spectrometer (SEM-EDS) for the major and minor elements, whereas electron probe micro-analysis (EPMA) was used for the estimation of trace element concentrations. Results confirmed the absence of unalloyed copper with a minimum tin content of 6% and a mean of 13% Sn. Lead values, however, with an average of 0.5% and absence of heavily leaded tin bronzes are closer to the XRF values from Nichoria as they contradict Jones' (1980) results. This further proved the over- or under-estimation of compositions during the analysis of corroded surfaces. Furthermore, two pins recovered from the early 10th century BC (Middle Protogeometric period) female burial within the apsidal building, which date somewhat earlier than the rest of the sample, were found to contain 1% arsenic in addition to 11% tin. Arsenic in the range of 1% could have easily resulted from the recycling and melting of Bronze Age arsenical copper or from the use of arsenical copper scrap in the tin bronze melt. Arsenic is a volatile metal, but it would still be present in the metal in small amounts even after repeated remelting. The arsenic bearing pins also fall in the higher tin range with which also matched the XRF Nichoria results and the trend for the gradual use of less arsenic and its complete absence in the Early Iron Age (Rapp *et al.* 1978, p. 179).

Overall, the analysis Lefkandi and Nichoria analyses confirmed the limited use of pure copper, a wide distribution in the tin contents, the presence of high tin bronzes, the occurrence of arsenic only as an impurity and a lack of correlation between artefact type and chemical composition. Rapp et al. (1978, pp. 175, 178) have suggested that the lack of correlation between composition and artefact function, together with the variable tin contents point to the relative lack of technological sophistication and the inability to produce consistent alloys. However, investigation with optical emission spectroscopy (OES) of production waste including copper prills from slags and metal drippings or splatter from melting (or smelting) operations from Nichoria showed *'that many if not most of the bronze artefacts came in finished form'* (Rapp *et al.* 1978, p. 180). Finally the hypothesis of bronze objects produced elsewhere and then brought on site would also account for the compositional variability.

Table 2.2. Summary of Kalapodi material grouping after composition characteristics and occurrence of objects according to chronological periods (after Riederer 2007, 414, table 41); emphasis on the 8th and 6th centuries is evident

centuries BC:	12th	11th	10th	9th	8th	7th	6th	5th	4th
metal/alloy period:	LBA			Geometric		Archaic		Classical	
unalloyed Cu				1	8				
Fe-rich Cu				1	11		1		
low tin bronze			1		9			1	
medium tin bronze		1		1	26	5	20	1	2
high tin bronze					6		2	1	
low leaded tin bronze					9	1	5	1	1
medium and high leaded tin bronze					1		8	4	
totals		1	1	3	70	6	36	8	3

A more recent excavation report from the sanctuary of Artemis and Apollo at Kalapodi in ancient Phocis by the German Archaeological Institute included analytical data of the copper-based objects (Felsch 2007). The report aimed to discuss the nature of the material recovered and to enhance the understanding of Early Iron Age copper-based metallurgy (Riederer 2007, p. 389). In order to address the above 185 objects dating from the Late Bronze Age to the Classical period have been selected for analysis with atomic absorption spectroscopy (AAS). The objects were safely dated in the range of one century and they belong to several artefact groups including tripods, vessels, shields and helmets, figurines, and jewellery articles such as armlets, rings, fibulae, pins, necklaces and earrings. A set of twelve elements was analysed and detection limits were rather low at 0.02% for bismuth, 0.01% for gold and as low as 0.001% for cadmium, and 0.2% for tin.

Furthermore, Riederer (2007, p. 389) argued that classifying all copper-based alloys as bronzes is not suitable in order to reveal the particularities of the Early Iron Age bronze technology and the samples were diligently grouped according to their respective compositions. Analysis of the material also aimed to identify any imported objects at the sanctuary of Kalapodi on the basis of their chemical compositions. Results once more confirmed the extended use of tin as the main alloying element. Hence, three groups of unalloyed copper were detected, namely one with lead impurities, a second with both lead and tin and a third with iron impurities. Similarly, tin bronze and leaded tin bronze objects were grouped according to the levels of the tin and lead contents found respectively into low (<5%), medium (5-10%) and high (>10%) groups (Riederer 2007, pp. 406–415) (Table 2.2).

Overall results shed that in the Geometric period and the 8th century BC a sudden increase in the frequency of copper/copper-based objects and the production of medium tin bronzes (5-10% Sn) occurred (Table 2). Average concentrations for the latter group showed a small increase in the tin content for the transition from the Late Bronze and the Early Iron Age (6.5% Sn) to the Geometric period in the 8th century BC. From the Geometric period onwards and into the Hellenistic, however, the tin content for the medium tin bronze group is consistent with an average of approximately 7.5% Sn (Riederer 2007, p. 412, table 37). Moreover, the iron-rich copper objects with iron contents up to 6.4%, form a distinct group that has been interpreted as imported to Kalapodi from elsewhere, whereas its place of origin is difficult to pinpoint (for also Chapter 8). For the rest of the assemblage, trace element concentrations are quite similar pointing possibly to the use of a single copper source over subsequent periods (Riederer 2007, p. 422). As also done by Craddock (1976, 1977), Rapp et al. (1978), and to a lesser extent by Jones (1980), quantitative data for Kalapodi have been discussed to in conjunction with artefact typologies. For example, all relief tripods have been found to consist of copper with tin, lead and iron impurities, whereas the figurines are typically of medium tin bronze with varying amounts of lead from impurity levels up to 10% Pb (Riederer 2007, pp. 391, 396).

Drawing away from excavation reports, Rolley et al. (1983) conducted a comparative examination of Early Iron Age tripods from Greece and the Near East in order to address the impact of technological knowledge transmission between mainland Greece and the Near East on artistic expression from the 8th century BC onwards. The influence of the more 'sophisticated' eastern bronze technology in Greece was investigated by the parallel study of 9th and middle 8th century BC tripods with late 8th century eastern imports and eastern imitations manufactured in Greece, i.e. orientalising objects. Tripods from Delphi and Olympia were analysed with atomic absorption spectroscopy (76 samples) acknowledging the heterogeneity of ancient metals and its possible effect on analytical results, while surface corrosion products were removed prior to analysis. Detection limit of the instrument was reported at 0.01% for elements such as gold and zinc, 0.1% for lead and iron, and 0.6% for tin (Rolley *et al.* 1983, pp. 115–117).

Results showed that the two groups of the 9th and early 8th centuries BC Greek tripods have low tin concentrations, typically below 2% Sn (1st and 2nd categories), as opposed to the eastern imports and orientalising tripods of the late 8th century which contain more variable and typically higher tin contents (3rd and 4th categories). Further observations were made regarding the tripods' manufacturing techniques, namely casting and cold working, and alloy composition. Tin contents of the tripods with cast legs and handles (3rd category) were found much more variable than in hammered tripods (4th category) whose tin content consistently falls in the range of 5-9% Sn (Rolley *et al.* 1983, pp. 117–118, fig. 1). For the lead content results suggested that it was possibly added according to the type of the object, but at the same time the variability in its values leaves open the question of its deliberate or not addition in the bronze melt for the Early Iron Age (Rolley *et al.* 1983, p. 127). Finally, changes in alloy composition were also linked to the introduction of new decorations imitating the elaborate Near Eastern styles.

Complementary analysis on the Geometric Greek, Near Eastern and orientalising tripods and other bronzes including shields and other types of cauldrons was conducted in order to trace any particularities of the different workshops in Corinth, Argos, Attica and Crete. Results showed certain preferences over metal composition which possibly point to the use of different copper sources for their production. Finally, it was found that better quality metal was used for the hammered tripods (Mangou *et al.* 1986, 1991).

Based on these results and on the much debated 'tin shortage theory', it was proposed by the authors that early Greek smiths did not have access to tin supply directly and that any tin present in the objects of the 9th and early 8th centuries resulted from the recycling of earlier Mycenaean bronze which upon remelting would have preserved its original tin content (Rolley *et al.* 1983, p. 127). According to this hypothesis, low tin bronzes would have also resulted from the mixing of Late Bronze Age bronze scrap metal with fresh copper and not from an intentional addition of small quantities of tin. However and as already mentioned, tin losses do occur during remelting.

It was also argued that apprenticeship of the advanced eastern metallurgical practices was achieved by *direct contact* between Greek and Near Eastern craftsmen that must have taken place in the years following the 8th century BC. Such interaction would have been the result either of Greek immigrants working in the East and bringing the foreign technology with them or the establishment of metal workshops on Greek land both by repatriated Greek or Near Eastern craftsmen (Rolley *et al.* 1983, p. 130). The above statements raise two very important issues much discussed in the long history of Mediterranean archaeology, namely the issue of a supposed period of stagnation following the collapse of the Mycenaean palace system and that of the mobility of craftsmen in the first half of the 1st millennium BC. The suggested mobility of craftsmen in the first half of the 1st millennium BC in the eastern Mediterranean triggered by technological specialisation (Zaccagnini 1983) and by contemporary geo-socio-political dynamics (Fantalkin 2006), has been well evidenced, while the permanent or temporary character of their stay and workmanship is still debated (Muhly 2005). All the same, the assumption that tin metal and associated technological know-how were *re*-introduced in mainland Greece following the 8th century is rather unsupported by the archaeological record, but also, as Muhly (1998, pp. 323–324) has justifiably noted it contradicts Rolley's previous position for the continuity of local metallurgical practices in the transition from Bronze to Iron Age (Rolley 1977).

2.4.1.1 Conclusion

From the above presentation of the published analytical data certain trends become apparent for Early Iron Age Greek copper technology, whereas particularities of the different assemblages still remain. The emerging picture includes an emphasis on tin as the main alloying component for the whole of the Early Iron Age and the scarcity of unalloyed copper. Lead is present mainly as an impurity early on such as in the Protogeometric assemblage from Lefkandi (Orfanou and Rehren forthcoming), but it was deliberately added from the Geometric period onwards and for specific artefact types such as the orientalising tripods of the 8th century BC (Rolley *et al.* 1983). When lead was intentionally added to tin bronzes no particular copper-tin recipe was preferred as it was added to various copper-tin ratios ranging between 1% and 22% tin as seen in the Kalapodi assemblage (Riederer 2007, pp. 413–414). Iron was the main impurity in the copper alloys, typically below 1% for the whole period as seen in the Lefkandi and Nichoria analyses (Rapp *et al.* 1978, Jones 1980), whereas iron-rich objects with up to 6% Fe found at Kalapodi were attributed to the choices of a particular workshop (Riederer 2007, pp. 408, 422). Analysis of the different artefact types showed that certain control over the production of certain artefact groups took place but not universally as indicated by the Nichoria analysis particularly for earlier periods (Rapp *et al.* 1978, p. 174, Kayafa 2006, p. 228).

2.4.2 Synthesis of available data

The above observations have raised scientific interest for the further exploration of the bronze technology of early Greece. Several overviews of the published data have tried to understand the development of this technology from the Late Bronze Age down to the Archaic and Classical periods. In addition, experimental work has been conducted in order to advance the understanding of ancient Greek bronze working and metal refining.

Kayafa (2006) investigated Late Bronze and Early Iron Age copper-based production concluding that a special metallurgical tradition formed in the Early Iron Age whose foundations can be traced in the preceding Mycenaean period (Kayafa 2006, p. 216) suggesting that socio-political change triggered technological change too. Kayafa also argued that for the first centuries of the 1st millennium BC a certain regionalism and uneven development which are reflected in the diversity of metallurgical customs and practices prevailed in mainland Greece. Furthermore, the late 11th and 10th centuries BC were an intermediate phase of hybrid practices during which often both iron and bronze were used as part of the same object such as iron pins with attached bronze globes (Snodgrass 2000, pp. 233–234) as iron technology was rather simultaneously introduced in in most parts of Greece such as Macedonia, central Greece and Crete (Kayafa 2006, p. 220). The availability of both these base metals and the immediate increase in the number of ore sources within mainland Greece that could be exploited, changed the way bronze was used and perceived. A much broader range of choices over their production was now available to Early Iron Age smiths which triggered a shift in the use of copper-base alloys and provided new ground for experimentation. Although this has not been universal copper and bronze were typically used for aesthetically pleasing objects such as jewellery, ornaments and votive offerings, whereas iron was reserved for more practical, everyday use implements such as tools and armour particularly after the ability of ironsmiths to produce steel (Jones 1980, p. 458, Kayafa 2006, p. 221).

Variability in chemical compositions and the existence of regional idiosyncrasies in alloy recipes suggest a small scale metallurgical production which was rather stable in alloy-making processes, as well as access to different metal sources (Muhly 1998, Kayafa 2006, p. 219). In the period following the Mycenaean palace collapse chemical analyses show no reduction in the use of tin which had become quite widespread from the Late Bronze Age onwards (Mangou and Ioannou 1999). Unalloyed copper and high tin bronzes with more than 15% tin are more often found as opposed to the preceding period during which the majority of the tin bronzes had a 5-15% tin content (Kayafa 2006, pp. 226–227). From the early Geometric period onwards arsenical copper was substituted almost completely by tin bronze, and ever since arsenic is to be found in copper-base objects only coincidentally (Papadimitriou 2001, p. 594). A marked change is only seen in the Geometric period during which the widespread deliberate addition of lead in the tin bronzes took place, whereas iron impurities are more prominently found. This has been often interpreted as an indication for the use of inferior quality metal, while iron could have also resulted from the use of iron-bearing fluxing agents during the smelting process (Cooke and Aschenbrenner 1975, Balthazar 1990, p. 76) or even from the practice of poorer refining techniques (Pernicka 1999).

The relation between the production techniques and the chemical composition of the objects is characteristic and more systematic for the Geometric period than in any preceding period of Greek antiquity. Different metalworking and decorative techniques including casting in clay/sand/metal moulds, hollow casting, lost-wax casting, cold or hot hammering, and incised or impressed decoration, were favoured and facilitated by different alloy recipes. The level of conscious decision making over alloy production having in mind the manufacturing technique of the object, however, deferred regionally. This was rather the result of a number of coexisting parameters such as raw material availability, the metalsmith's skills and the ability to control these resources. Signs of such control were introduced in earlier periods too, but it was only in the Geometric period that they acquired characteristics of a deliberate and systematic mode (Papadimitriou 2001, pp. 589–590). Finally, standard deviation for the average tin concentrations, as measured from analyses by Craddock (1976, 1977), has been progressively reduced from the prehistoric to historic periods to about 20-30% for the Archaic period suggesting the gradual more successful monitoring and control over the alloying of copper with tin (Karydas 2007, p. 426).

Furthermore, Papadimitriou (1992, 2001) investigated tin bronze technology of mainland Greece from the Geometric period by reviewing the material previously analysed by Rolley et al. (1983) and Mangou et al. (1986, 1991). Emphasis was not put on the impact of the Near Eastern contacts, but also drawing from the complementary analyses by Mangou et al., he was rather interested in the investigation of the technical characteristics of the Greek bronze technology and the particularities arising from the exploitation of local ores. A distinction between hammered and cast objects was made and the different features of each group were delineated. Review of these data showed that hammered objects consisted of a much better quality metal than in castings. Average iron concentration for the hammered objects was found as low as 0.45% with 50% of the objects' iron content below 0.2%, whereas castings contained consistently more iron with an average of 1.1%. For the hammered objects lead was found at impurity levels pointing to its unintentional presence.

In an attempt to account for the negative correlation between the higher tin and low iron values for the hammered Geometric tripods, Papadimitriou suggested the possible addition of cassiterite, instead of tin metal, to unrefined copper that would act as a single refining and alloying step

(Papadimitriou 1991, pp. 121–123, 2001). The addition of cassiterite (SnO_2) in the copper under neutral or slightly oxidizing conditions would allegedly act as an oxidizing agent that would assist in removing the excess iron and its dissolution in the slag. This reaction might be *'thermodynamically possible'* according to the following formula ($2[\mathrm{Fe}]_{\mathrm{Cu}} + \mathrm{SnO_2} \rightarrow [\mathrm{Sn}]_{\mathrm{Cu}} + 2(\mathrm{FeO})$) and the hypothesis *'statistically verified'* (Papadimitriou 1991, p. 122, 1992, pp. 115–116), but archaeologically such a suggestion is still rather unsupported since cassiterite has been rarely found in archaeological sites (Charles 1978, p. 25, Haustein *et al.* 2010, p. 830) such as in Late Bronze Age Sardinia (Cambi 1959, Charles 1978, p. 27). Although it is possible that for the Early Bronze Age tin was added in copper in the form of cassiterite since evidence of tin metal is scarce (Charles 1980, Muhly 2005), for later periods of the Greek Bronze Age tin may have been added as tin metal (Charles 1978, p. 25, Gale and Stos-Gale 1982, p. 13), whereas available Iron Age evidence suggests that the addition of cassiterite is unlikely to have taken place. The Late Bronze Age tin ingots recovered from the cargos of the Cape Gelidonya and Uluburun shipwrecks further support the circulation and handling of tin in its metallic form in eastern Mediterranean for subsequent periods including the Iron Age (Bass 1967, 1973, Pulak 1998). According to Muhly (1985, p. 278) the addition of tin in its oxide form directly to the copper and their mixing in a crucible under reducing conditions, i.e. covered with charcoal, in a single operation would have been possible but, at the same time, such a process would be difficult to control, the alloying would have been erratic and it would result in a product of uncertain composition. Nonetheless, bronze production by addition of cassiterite would still be better controlled than the smelting of the arsenic-bearing copper ores, which vary greatly in their arsenic content, for the production of arsenical copper, since cassiterite typically contains approximately 78% tin (Cathro 2005).

Finally, Papadimitriou's suggestion is based on the statistical investigation of only one artefact type, i.e. the tripods, which belong to different periods and workshops from several parts of Greece and the Near East. To project the above observations to a broader time span and a multiregional practice of Greek bronze technology as a whole would be effectively misleading. On the basis of both archaeological evidence and archaeometric data for the case of the Geometric tripods it could be argued that more systematic refining of the copper took place for the metal that was intended for hammering and that tin was added intentionally only to good quality copper to increase hardness, but not brittleness.

In the following chapter, the methodology of the present study and the analytical instruments' particularities are discussed in detail in order to address issues of results' reliability and comparability and to avoid some of the misconceptions of previously published datasets.

Part II

Chapter 3. Materials and Methods

Below, the copper-based assemblage from Pherae examined for the needs of the study is discussed in detail. It consists of a numerous bronze offerings dating to the first half of the 1st millennium BC and has been recovered from two deposits in close proximity to the temple at the sanctuary of Enodia and Thavlios Zeus. The sampling strategy of this massive assemblage and analytical methodology of the selected samples have been designed to address the archaeological questions put forward and to incorporate the characteristics of the assemblage as a whole. Particular attributes of the wide range of artefact types and the state of preservation and the effects of corrosion processes on the metal objects caused during their long-term burial have been also taken into consideration.

3.1 Votive bronzes from the sanctuary of Enodia

The assemblage of bronze votive offerings from Pherae consists of several thousand artefacts which are jointly kept at the National Archaeological Museum in Athens and Athanasakeio Archaeological Museum of Volos, in Greece. Even though it is not easy to calculate the exact number of objects recovered, it is estimated to 7,000 (estimation after recording of material in the storage rooms of both museums in 2010). The assemblage was recovered in the two excavation seasons of 1925-6 by Béquignon and Arvanitopoulos on behalf of the French School and the Greek Archaeological Service respectively (Béquignon 1937), and 2006-7 by Intzesiloglou and Arachoviti on behalf of the 13th Ephorate of Antiquities of Volos (Intzesiloglou and Arachoviti pers. com. 2009).

Figure 3.1. Copper-based artefact from the sanctuary of Enodia as exhibited at the Athanasakeio Archaeological Museum of Volos (new wing exhibition)

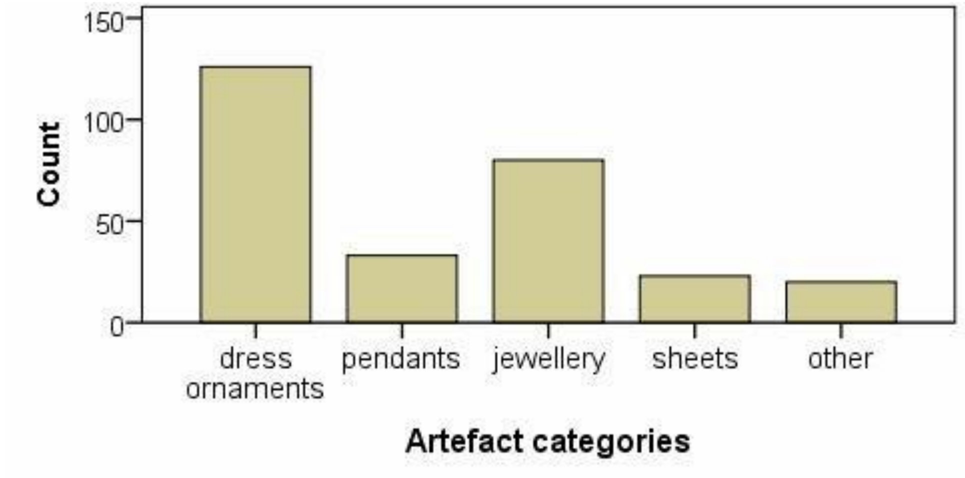


Figure 3.2. Bar chart showing artefact categories present in the sample (total= 282)

The assemblage is quite diverse in its typology as it includes a wide range of artefact types (Figure 3.1). Nonetheless, an emphasis on objects of decorative character and personal adornment (Figure 3.4) is evident as artefact types with the most occurrences include fibulae, rings, and pendants which are present in thousands (Figure 3.5). Notable position holds the group of Macedonian bronzes which is linked with the Balkan region and northern Greece. Macedonian bronzes have a wide circulation in mainland Greece from Macedonia where they are found in abundance which also justifies their name, to the Peloponnese where they are present in all major sites including Olympia, Tegea, Sparta and Perachora (Bouzek 1997, p. 110, figs. 111-113). Additional artefact types include vessels and fittings, horse figurines, bracelets and arm bands (armlets), earrings, lockers, tweezers, whorls, chains and nails (Table 3.1).

Figure 3.3. Double-axe pendant AE 749 recovered at the sanctuary of Enodia

The votives dedicated to Enodia and Thavlios/Afrios Zeus have an overall symbolic character, but they also reflect the interests and livelihood activities of their dedicators including aspects of personal and collective identity. Thus, hen, peacock, duck and waterfowl pendants have been justifiably symbolically linked with hunting activities at the neighbouring Lake Boebe (Figures 1.5-6), whereas horse and other animal figurines would stand for one of Thessaly's strongest assets, namely horse and cattle breeding. Similarly, miniature double-axe pendants (Figure 3.3) could possibly reflect aspects of socio-political organization of Thessalian communities in certain unrestful periods since from at least as early as the Classical period the double-axe was a symbol for the Thessalian *'tageia'*, i.e. periods of crisis and/or war preparation when a single commander (*tagos*) was appointed to control the whole plain (Helly 1995, Sordi 1997). Finally, several different types of fibulae are present which can be typologically linked to different regional workshops of mainland Greece but also to the southern Balkan region, Asia Minor and Italy (Blinkenberg 1926, Kilian 1975).

Figure 3.4. Reconstruction of a Geometric burial from Amphikleia, Attica, rich in bronze votive offerings similar to those found at Pherae (Proskynitopoulou 2009, p. 12)

3.1.1 Dating of the assemblage

The Pheraean assemblage fits well into the Early Iron Age cultic tradition and particularly that following the 9th century when bronze votive dedications accumulated by the thousands and monumental temples were erected at the sanctuaries of mainland Greece and the islands (Dickinson 2006a, p. 236). Close parallels to the Pheraean bronzes can be found in assemblages recovered from contemporary sanctuaries of this period such as these of Athena Alea at Tegea and the Argive Heraion in the Peloponnese, whereas an even tighter relationship both typological and geographical is evident with the sanctuaries at Philia in Thessaly, and Kalapodi and Delphi in Phocis (Kilian 1975, pp. 8–10, Voyatzis 1990, Snodgrass 2000, p. 275, Felsch 2007).

Even though the deposition of vast amounts of bronzes in the form of religious offerings during the first half of the 1st millennium BC is well illustrated in the archaeological record of early Greece, a narrower dating of these assemblages either as a whole or of specific artefact types is indeed quite challenging. This is a result of both the absence of stratigraphic sequences within these deposits and the long-lived character of many artefact types' production and use. These deposits did not form in the course of long periods. Instead they were rather single episodes which intended to host offerings that had accumulated within the consecrated space over long periods of often a few hundred years (Snodgrass 2000, p. 276). In addition, many artefact types to be found in sanctuary deposits were in circulation for a good part of the Early Iron Age and even as late as the Classical period including certain fibulae and ring types such as the open rings with simple round cross-section (Appendix I, Type Ia, Figure 3.6) and the spiral rings which have been recovered from contexts dating from the Bronze Age down to mid-1st millennium BC (Vokotopoulou 1990, pp. 61, 66, Souyoudzoglou-Haywood 1999, pp. 34, 81). Moreover, the production of many fibulae types present at EIA Pherae often covers a time span of more than a century, thus, covering many phases of the Geometric and Archaic periods as in the case of Thessalian bow fibula Kilian type D IIIk (Kilian 1975, pl. 20) which is dated from the middle Geometric to the Archaic period.

a) 

b) 

Figure 3.5. A) Boeotian and Epirotic fibulae (left) and B) Type IVa rings (right) at the National Archaeological Museum in Athens

Figure 3.6. Ring AE 261 with open endings and simple round cross-section (Type Ia)

Additional dating issues arise due to the potentially complex object life-histories of the votive offerings which often involve recycling and reuse. Objects produced at a certain period but used for long time spans that often exceed the lifetime of their owners is a phenomenon often encountered in Greek antiquity such as, for example, a seal and a gold pendant with Syrian parallels dating to the early 2nd millennium BC which have been found at the Early Iron Age Toumba cemetery at Lefkandi suggesting their circulation for already a millennium before their final deposition as grave offerings (Lemos 2000, p. 15, Kroll 2008, p. 37).

Despite the aforementioned obstacles in the dating of bronzes from sanctuary deposits of early Greece, relative chronological sequences established through the investigation of typologies and comparison with securely dated assemblages are potentially a starting point. Detailed typological studies conducted throughout the 20th century for certain artefact groups such as the fibulae (Blinkenberg 1926, Kilian 1975), the bird pendants (Voyatzis 1990) or the horse figurines (Zimmermann 1989) can prove a useful resource to the study and dating of such mixed assemblages. In addition, finds from contemporary burial or other closed contexts which are generally better dated provide rather useful dating proxies. Even though in Bronze Age tradition burials often have more than one phases of use resulting in a collection of multi-period grave-goods, the changing pattern towards single burials in the Early Iron Age when reuse of tombs became rarer contributes further (Dickinson 2006a, pp. 179, 183–185). The archaic tombs of Aeneia (Vokotopoulou 1990), and the cemeteries of Vitsa and Agrosykia in northern Greece (Vokotopoulou 1986, Chrysostomou 2007), as well as the Geometric tholos tombs in Thessaly (Arachoviti 1994) are examples with contained bronze grave-goods that provide parallels to the Pheraean assemblage.

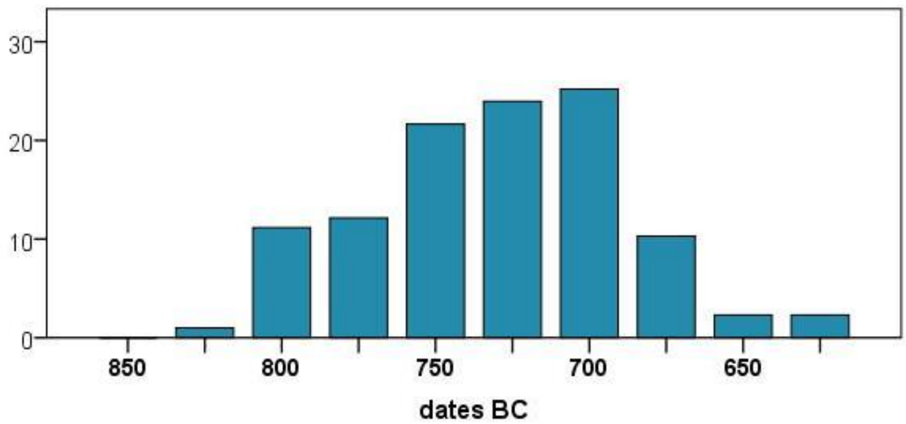
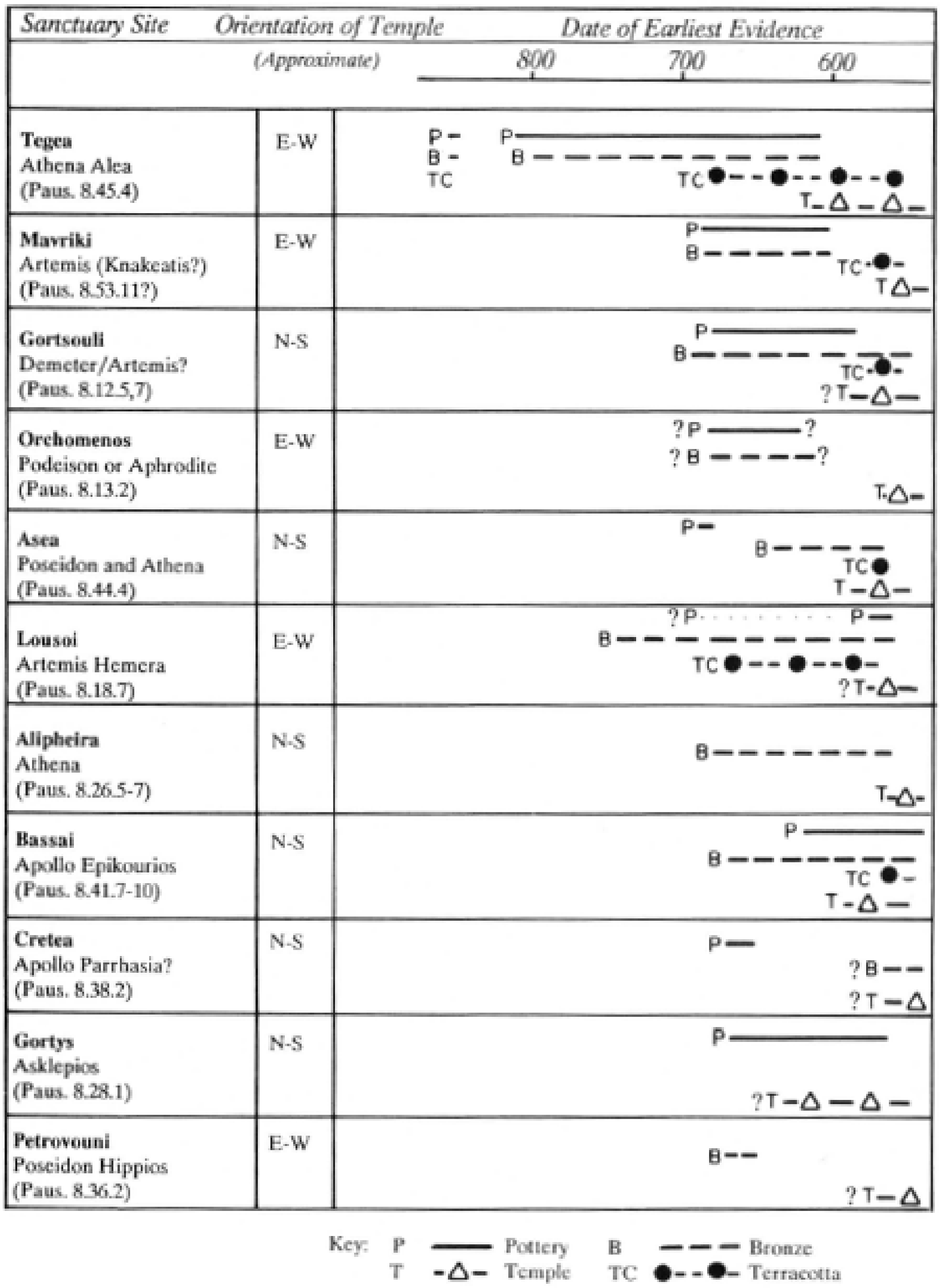


Figure 3.7. Chronological distribution of the diagnostic fibulae (n= 110) according to their typology which covers the time span from the Early Geometric to the Archaic periods (825-600 BC); absolute dating for Thessaly after Coldstream (2003) and Snodgrass (2000); fibulae dating after Kilian (1975) and Blinkenberg (1926)

Classification of the Macedonian bronzes by Bouzek places the peak of the symbolic depositional activity between the 8th and mid-6th centuries BC when bronze dedications accumulated by the thousands. Accordingly, Macedonian bronzes from Pherae date both to the early stages of their presence in the Greek mainland from the early 8th century onwards, i.e. Bouzek's 'earliest' type, and to the 6th century BC 'manneristic' style (600-550 BC) (see also Appendix I, Figure I.29) (Bouzek 1997, p. 110, figs. 111-113).



Sanctuary Site	Orientation of Temple (Approximate)	Date of Earliest Evidence (800 / 700 / 600)
Tegea Athena Alea (Paus. 8.45.4)	E-W	P; B; TC; T
Mavriki Artemis (Knakeatis?) (Paus. 8.53.11?)	E-W	P; B; TC; T
Gortsouli Demeter/Artemis? (Paus. 8.12.5,7)	N-S	P; B; TC; ? T
Orchomenos Podeison or Aphrodite (Paus. 8.13.2)	E-W	? P ?; ? B ?; T
Asea Poseidon and Athena (Paus. 8.44.4)	N-S	P; B; TC; T
Lousoi Artemis Hemera (Paus. 8.18.7)	E-W	? P; P; B; TC; ? T
Alipheira Athena (Paus. 8.26.5-7)	N-S	B; T
Bassai Apollo Epikourios (Paus. 8.41.7-10)	N-S	P; B; TC; T
Cretea Apollo Parrhasia? (Paus. 8.38.2)	N-S	P; ? B; ? T
Gortys Asklepios (Paus. 8.28.1)	N-S	P; ? T
Petrovouni Poseidon Hippios (Paus. 8.36.2)	E-W	B; ? T

Key: P Pottery; T Temple; B Bronze; TC Terracotta

Figure 3.8. Table showing the phases of use of Arcadian sanctuaries in the Geometric and Archaic periods (Voyatzis 1990, figure 7)

The sanctuary of Enodia had a long period of use covering most of the 1st millennium BC from the Protogeometric down to the Hellenistic period and the Roman occupation of Thessaly (Doulgeri-Intzesiloglou 2000, 2006). The two deposits themselves have been linked to the construction phase of the Archaic temple (Østby 1994). Macroscopic examination of the bronzes assemblage and comparison with the assemblages of the sanctuaries of Athena Alea at Tegea, Isthmia, Olympia and Kalapodi (Philipp 1981, Voyatzis 1990, Raubitschek 1998, Felsch 2007), as well as with published typologies (Kilian 1975, pp. 186–187) and contemporary burial contexts point to an emphasis on the Geometric, Sub-geometric and early Archaic periods (Figure 3.8). A dating peak for the fibulae in the analysed sample based on established typologies is found at the late 8th and 7th centuries BC (Figure 3.7). These dates are a result of combining the major typological publications of Blinkenberg (1926) and Kilian (1975) with absolute chronologies for Thessaly put forward by Coldstream (2003) and Snodgrass (2000). Nonetheless, dates for the whole assemblage are broader as certain bronzes date as early as the Protogeometric and Sub-protogeometric periods in the late 10th and 9th centuries, but also later in the Archaic period and the 6th century BC.

3.1.2 Provenance of votive offerings and regional workshops

Artefacts with both local and non-Thessalian typologies and features are present at the Pheraean assemblage.

3.1.2.1 Local material

Despite the artefacts' morphological variations, pinpointing the exact *loci* of their production or the origin of their users is a rather challenging task to which limitations apply due to the nature of the assemblage and the circumstances of its discovery (see above this Chapter). Thus, the majority of the objects have a local character pointing to the activity of Thessalian copper metallurgical workshops. This is, for instance, well-illustrated in the group of Thessalian fibulae which consists of hundreds of objects recovered from the Enodia sanctuary and contemporary burial contexts (Blinkenberg 1926, pp. 110–128, Kilian 1975, p. 186, Arachoviti 1994) (Figure 3.9). Furthermore, a number of additional object types with simpler form such as fittings, rings, pendants, nails, whorls and decorative tubes are present in the Enodia assemblage (Figure 3.6) which even though it is difficult to attribute to a particular workshop, it is reasonable to argue that Thessalian craftsmen able to produce high quality fibulae were also in a position to manufacture these objects as well. Pherae was an active production centre at least during the Hellenistic as indicated by evidence of pottery and lead workshops, while traces of an Archaic bronze workshop including tuyère and crucible fragments have been also found providing evidence that is able to account for the local production of a large part of the bronze votive offerings assemblage (Doulgeri-Intzesiloglou 1992, 1994, p. 78, Asderaki-Tzoumerkioti and Rehren 2006) (see also Chapter 1.2.4.3).

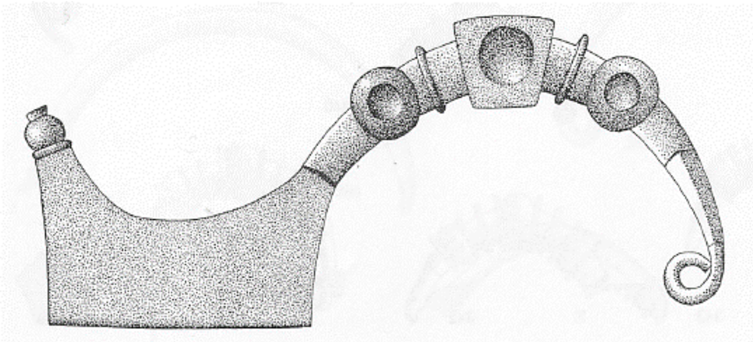


Figure 3.9. Drawing of Thessalian fibula NAM 594 (after Kilian 1975, pl. 11, no. 304)

3.1.2.2 Imported elements

Pherae was on the main crossroads and to be found by travelers crossing Thessaly, but it also controlled the only port of Thessaly, namely Pagasae, and hence Thessaly's communication with the Euboea and the Aegean (di Salvatore 1994, Coldstream 2003, pp. 43–44). Consequently, the presence of votive offerings with prominent foreign characteristics are also present at Pherae which are possible indicators for cultural contacts with non-Thessalian and even non-Greek communities is not surprising. Objects which reveal external influences could come both as imports on site and as local imitations of non-Thessalian objects since typological links with certain stylistic workshops are not necessarily straightforward geographical indicators too. The imitation of foreign objects from local workshops has been often attested in Early Iron Age Greece as, for example, at the Arcadian sanctuary of Athena Alea in Tegea where bird pendants incorporating Laconian and Argive features were locally produced (Voyatzis 1990, p. 153), whereas similar hybrid bird pendants have been found at Pherae too, such as the pendant M 1683.1 (Figure 3.10). Finally, distinct fibulae types such as the spectacle-, plate- and bow- fibulae with typological links to metalworking traditions of the Balkans, central and northern Greece respectively are all widely represented at the Pheraean assemblage (and in the sample), while additional types represent Italian, Near Eastern and Egyptian workshops (see also Figure 7.20).

Figure 3.10. Bird pendant M 1683.1 from the Enodia sanctuary combining Laconian and Argive features (drawing after Kilian 1975, pl. 85.12)

Finally, even if the objects' exact provenance could be established this would not straightforwardly provide a clear indication as to who has been actually using and/or has deposited them to the sanctuary. Mobility of people and ideas in the Mediterranean has been the focus of rigorous scholarly which largely agrees that expressions of social exchange are rarely straightforward since they are governed by processes of 'hybridization, co-presence and conflict' (Knapp and van Dommelen 2010, p. 2) and assimilation of the imported elements' 'otherness' (Panagiotopoulos 2012). Thus, a fibula with typological links to Egypt or the Near East could have been brought to Pherae by a foreigner or a Thessalian travelling abroad, as it could have equally ended up at Pherae after changing several hands over short or longer periods. Meanwhile, it would have potentially been incorporated by the cultural reality of Pherae to varying degrees. Alternatively, the possibility of locally produced objects at Enodia sanctuary deposited by non-Thessalians as more suitable offerings to the national Thessalian goddess should be also considered.

Finally, for a detailed discussion of the artefact typologies, attribution to different regional workshops, dating and parallel finds see Appendix I.

3.2 The sample and sampling strategy

Following the macroscopic investigation of the assemblage, a sample of 282 objects and fragments of objects was selected for analysis (see below Chapter 3.3). The total number of copper-based objects recovered at the sanctuary of Enodia has not yet been established and as already mentioned it is only estimated that 6 to 7k objects are included in the assemblage. This is to be attributed to the fact the assemblage is divided between two museums and its cataloguing and recording is at different stages. In addition, to the uncertain number of objects, due to incomplete cataloguing of the assemblage totals for the different artefact types and categories are not clearly listed in the museum catalogues. Thus, a strictly stratified sampling strategy was not possible to be adopted for the present study. Instead, the main criterion for the sampling strategy was the representation of the numerous artefact types to be found in the assemblage as these were observed at the collection stored at the Archaeological Museum of Volos in summer 2010 since the sampling permission was granted from the latter and not from the National Archaeological Museum in Athens.

Since a sample that would immediately reflect in percentages the absolute numbers of artefact types was not possible, the selected sample aimed to represent most artefact types/categories observed in the Volos assemblage even if that was with few occurrences. For example, fewer tweezers and horse figurines in the sample reflect their rarity in the excavated assemblage as well, whereas from the most multitudinous types such as the fibulae, rings and pendants more samples have been selected. Overall, artefact categories most often found both in the sample and the original assemblage include dress ornaments, decorative articles, pieces of jewellery and pendants (Figure 3.2, Table 3.1).

Additional sampling criteria applied to the objects selected for surface or invasive analysis, namely pXRF or EPMA/OM respectively (see below Chapter 3.3 on analytical methodology). For surface, non-invasive analysis there have been selected artefacts with overall good preservation state since no samples needed to be removed. In total 212 objects were selected which featured only a thin patina or otherwise few other corrosion products and which were typically complete or at least their typology was clearly discernible. This allowed for the analysis of a significant number of artefacts that could be attributed to specific metalworking workshops/traditions without disturbing the physical integrity of the objects themselves. For the purposes of invasive analysis mostly objects already fragmented were selected as small cut samples needed to be removed from the artefacts (see below Chapter 3.3.2). The invasive sample was smaller (n=70) than the non-invasive one as cutting samples, however small, from museum collections should be limited to the absolute necessary number of objects. Thus, it was deemed that these seventy cut samples represented the heterogeneity of the whole assemblage as observed in the collection kept at the Archaeological Museum of Volos. Finally, the total number of sampled objects were selected having in mind the object types present and not the total number of artefacts recovered or catalogued. Overall, a clear object typology along with a large number of artefacts analysed, as well as a substantial number of low detection limit analyses (0.01 wt%) were imperative for addressing the research questions posed by the present study. Finally, it was

The sample was then divided into '*categories'* and '*types'*, i.e. several artefact types fall under one category (Figure 3.11). The fibulae and rings are the two artefact types with the most occurrences both in the sample and the assemblage with 119 and 56 samples respectively. Particular emphasis has been put on the fibulae since they can be grouped typologically with relative accuracy in different regional workshops (see also Appendix I).

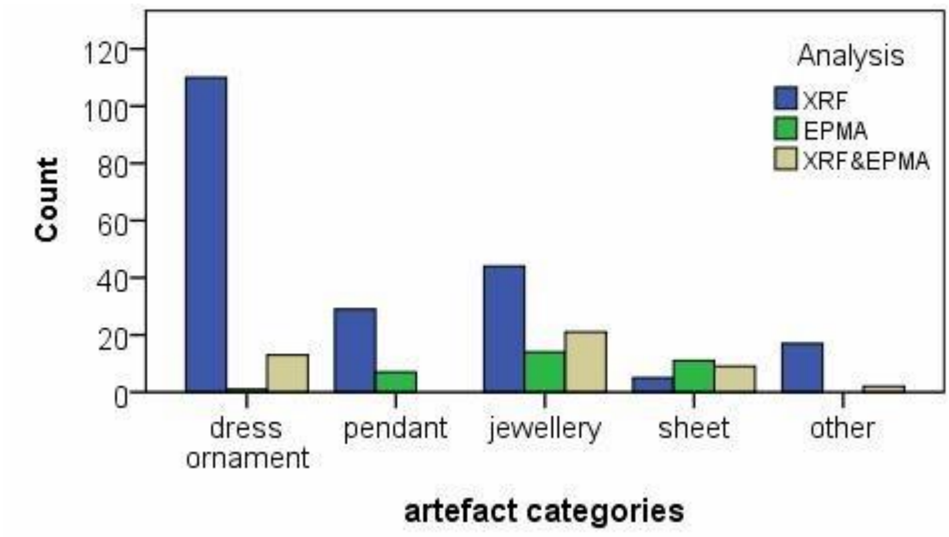


Figure 3.11. Objects according to category as analysed with pXRF, EPMA or with both techniques

Artefact types represented with fewer samples include vessels, metal sheets and fittings as parts of different objects, nails, tweezers, whorls and figurines. Finally, fragments of objects whose complete form, shape and/or use was not possible to define have been also selected for invasive analysis since they raised fewer sampling issues as opposed to the complete objects, whereas investigation of their composition and manufacturing techniques would contribute in the general understanding of this Early Iron Age assemblage.

Overall, twenty-two artefact types which fall into four artefact categories have been sampled with an additional fifth 'other' category for samples with single or just few occurrences and undiagnosed finds (Figure 3.2). Of these, 212 and 70 objects were selected for surface and invasive analysis respectively, while a set of 41 samples has been comparatively examined with both analytical methodologies (Figure 3.12).

Table 3.1. Summary table of the artefact categories and types present in the sample

artefact categories	artefact types	*n*	*n* (%)	Categories (%)
dress ornaments	**fibulae**	**119**	**42.2**	**44.7**
	pins	**7**	**2.5**	
jewellery	**rings**	**56**	**19.9**	**28.4**
	bead	**1**	**0.4**	
	arm bands	**16**	**5.7**	
	syringe	**1**	**0.4**	
	spiral rings	**6**	**2.1**	
pendants	**bird**	**15**	**5.3**	**11.7**
	biconical	**5**	**1.8**	
	double-axe	**1**	**0.4**	
	wheel disks	**7**	**2.5**	
	undiagnosed	**5**	**1.8**	
sheets	**sheets**	**17**	**6.0**	**8.2**
	vessel rim	**2**	**0.7**	
	metal bands	**4**	**1.4**	
	decorative ornaments	**5**	**1.8**	
other	**horse figurine**	**1**	**0.4**	**7.1**
	vessel	**1**	**0.4**	
	vessel handles	**2**	**0.7**	
	nails	**4**	**1.4**	
	tweezers	**2**	**0.7**	
	undiagnosed	**5**	**1.8**	
total		**282**	**100**	**100**

3.3 Analytical methodology

For the archaeometric investigation of the metal offerings from the Enodia sanctuary both invasive and non-invasive analytical approaches were conducted as already mentioned above. In this section the analytical instruments and protocols used are presented in detail (3.3.1 and 2), followed by a comparative account of both analytical methodologies outlining the issues between surface and invasive analyses (3.3.3) and a critical examination of the effect of corrosion products on archaeological copper-based objects (3.3.4).

Methodology incorporated the formulated archaeological questions (see Introduction) and the nature of the assemblage including the circumstances of the artefacts' production, its broad dating (9th-6th centuries BC with few objects possibly dating earlier) and the presence of multiple typological groups and artefact types. In addition, an effort was put so that the maximum amount of information was extracted from the sample, with the minimum physical alteration of the objects themselves (see also sampling strategy above, 3.2). Thus, the majority of the objects in the sample were analysed following a non-invasive strategy which involved the use of a portable X-ray fluorescence spectrometer (pXRF), whereas from fewer artefacts small samples were cut and examined with electron-probe microanalysis (EPMA). Small samples were removed from already broken and fragmented objects, whereas pXRF analyses took place typically on whole, well-preserved artefacts (Figure 3.9, b). A selection of objects was analysed with both pXRF and EPMA in order to test the comparability of results produced by the two instruments. Prior to invasive quantitative analysis (EPMA), preliminary metallographic investigation on the samples took place in order to examine any traces of metalworking techniques employed during the objects' production and to establish their state of preservation.

3.3.1 Non-invasive analysis: pXRF

Surface quantitative analysis of 253 objects took place at the Metals Conservation Laboratory of the 13th Ephorate of Prehistoric and Classical Antiquities in Volos, namely the 212 objects selected for surface analyses and the 41 samples cross-examined with EPMA (see also below Chapter 3.3.3). Prior to analysis a thin layer was scraped off from a small area of the objects' surface in order remove any corrosion products and reveal the sound metal (Figure 3.13). Following analyses, the objects' original appearance would be restored following a risk-free conservation treatment (Asderaki-Tzoumerkioti, pers. com.).

X-ray Fluorescence spectroscopy (XRF) is based on the principle that when an atom is hit with high energy X-rays, certain electrons of that atom are excited and forced to leave their original orbital for a higher one. This electron dislocation renders the electronic structure of the atom unstable. Electrons of a higher shell fall into the lower shell to fill in the gap left behind and reinstate the atomic balance. This selective excitation results in the emission of X-ray photons (fluorescence) the wavelength of which is characteristic for each element. The energy released and measured by the instrument is equal to the energy difference of the two shells involved in each atom (Goffer 2007, Pollard and Heron 2008). X-ray fluorescence is widely used for elemental and chemical analysis of inorganic materials such as metals, glass and ceramics in archaeology and it often is preferred by archaeologists, curators and conservators alike due to its non-destructive and relatively low-cost character (Tite et al. 2002, Henderson and Manti 2008). Currently a growing number of researchers gain access to and use pXRF equipment for the archaeometric study of metal artefacts due to the relatively low cast of the technology (Angelini *et al.* 2006, Kantarelou *et al.* 2007, Karydas 2007, Dussubieux *et al.* 2008, Shugar and Mass 2012, Shugar 2013, Charalambous *et al.* 2014).

Figure 3.12. A) Ring AE 95 with five projections and round cross section, B) double-axe pendant AE 749); the scraped point of the analysis with pXRF is visible by its bright metallic colour

For the surface analysis a portable, though not handheld, ED-XRF spectrometer developed at the Institute of Nuclear Physics, NCSR Demokritos (Figure 3.13) was used. The pXRF consisted of a Rh-anode side-window low power X-ray tube (50 Watt, 50 kV, 1 mA, 125 lm Be window), a PIN X-ray detector with 240 eV FWHM at MnKa and a 300 lm nominal crystal thickness and a battery operated multichannel analyser (MCA) card. The spot beam used during analyses had a width just under 3 mm (Karydas et al. 2004, pp. 19–20, Karydas and Asderaki-Tzoumerkioti 2011, p. 571). The analytical range of this portable XRF spectrometer extends from Z=14 (silicon) up to Z = 92 (uranium). The device can operate under two distinct conditions: one unfiltered mode with the voltage set at 15 kV, and a filtered one with the voltage set at 40 kV which was also used for the analyses presented here. Two laser pointers are mounted in the spectrometer head in such a way that the intersection point of their beams coincides with the cross-point of the incident X-ray beam axis and the detector axis. The spectrometer head is attached in an X-Y-Z position, allowing its easy movement in the X-Y directions (for more details on the XRF technique see also Karydas 2007). The instrument's performance was found to be stable over the duration of the study, and accuracy and precision levels were repeatedly found satisfactory with a coefficient of variation (CV) for bronze (BCR 961) analysed with pXRF of 0.5% for Cu and 6.2% for Sn, and δ relative of 0.03% and 1.53% for Cu and Sn respectively. For the minimum detection limit (MDL), even though no absolute values can be given, a realistic MDL for the XRF would be placed at 0.1% (see also below 3.3.1.1) which also is in agreement with most ED-XRF instruments which are usually able to detect these levels for any particular element (Pollard *et al.* 2007, p. 104). All the same, lower accuracy levels on the whole are expected for such low concentrations.

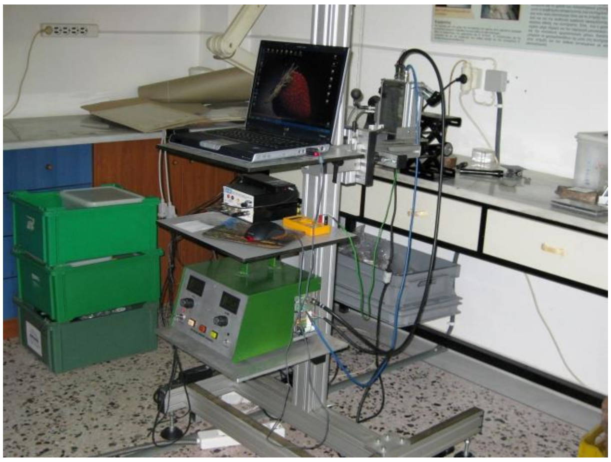


Figure 3.13. The pXRF instrument at the Metals Conservation Laboratory at the 13th EPCA in Volos

A set of eight elements was analysed for every sample, namely copper, tin, lead, arsenic, iron, nickel, zinc and antimony and during each analysis, 300 seconds (5 min) were allowed, whereas at least two spot analyses were conducted per sample. Taking into consideration issues of ancient metal heterogeneity caused either during manufacture or by post-depositional oxidation (Caley 1964, Charles 1973, p. 105), spot measurements were taken in different areas on the surface of each sample to obtain more representative chemical compositions. Selection of these areas depended largely on the objects' size, shape and state of preservation.

3.3.1.1 Standards; precision and accuracy

Four certified reference materials (CRMs), namely BCR-691 A, B, D and E, of known compositions have been analysed along with the samples. These standards consist of copper alloy discs of a diameter of 35 mm and thickness of 2 mm. Analysis of the BCR discs was conducted daily under the same operating conditions as in the samples in order to monitor issues of instrument stability and reproducibility of results.

Values for the copper and tin contents, which are the main components of both the CRMs and the samples, were found satisfactorily accurate and precise (Table 3.2). Main feature has been the repetition and consistency of the values given by the instrument, demonstrating good precision levels with a coefficient of variation (CV) of 0.5% for Cu and 6.2% for Sn, and δ relative of 0.03% and 1.53% for Cu and Sn respectively.

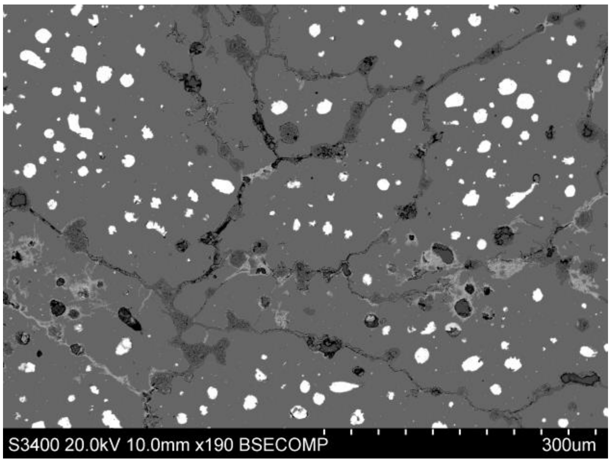


Figure 3.14. Back scatter image of ring AE 784; lead prills (white) are visible in the microstructure

Low accuracy levels for the elements with very low concentrations in the standards (< 0.16%), such as the zinc content of discs D and E or the arsenic content of disc B, are most likely the result of the pXRF instrument's specifications. Finally, the fact that certified values of the CRMs were produced by 5 mm diameter area analyses, as opposed to areas of just below 3mm which were examined with the pXRF could have also played a role in the variation between certified and analysed values.

Finally, notable variation takes place between the certified and analysed values for the lead content and lead analysed with the pXRF was repeatedly found in higher concentrations than the ones of the standards used. However, it is worth noting that significant variations in the certified and analysed results with the pXRF only took place when high concentrations of lead were present. For certified lead contents of 8% and 9% the pXRF instrument detected on average higher values of 40-60% additional to the certified ones, i.e. 11% and 15% Pb respectively (BCR-691 A and D) (Table 3.2). For BCR-691 E with a lead content of just 0.2% a marked decrease in the analysed lead value is visible of just 40% of the certified value (0.08% Pb mean). However, a lead value of 0.2% Pb would be quite close the instrument's detection limit and, in fact, in a couple of measurements the instrument did not detect any lead at all. Consequently and on the basis of BCR-691 B disc analysis, it is seen that the instrument produced reliable lead values regarding trace element concentrations. Despite these large variations in the lead-rich objects, certified and analysed values of the lead content for a brass with lead traces were quite accurate with only an 8% increase on the lead for analysed values (BCR-691 B).

Table 3.2. Analysis of the four CRM BCR-691 discs during examination of the material (σ= standard deviation, CV= coefficient of variation, n= number of spot analyses)

BCR-691 Disc		% Cu	% Zn	% As	% Sn	% Pb
A	**Leaded bronze**					
	mean (n=11)	77.08	5.62	0.18	6.26	10.86
analysed	σ	0.93	0.33	0.03	0.42	0.92
	CV (%)	1.20	5.82	14.70	6.64	8.51
	BCR	**78.73**	**6.02**	**0.19**	**7.16**	**7.90**
certified	δ abs	1.65	0.40	0.01	0.90	2.96
	δ rel (%)	2.10	6.67	7.03	12.53	37.51
B	**Brass**					
	mean (n=9)	84.08	13.33	0.23	2.00	0.36
analysed	σ	0.61	0.54	0.01	0.23	0.13
	CV (%)	0.73	4.06	6.02	11.63	36.90
	BCR	**82.65**	**14.80**	**0.10**	**2.06**	**0.39**
certified	δ abs	1.43	1.47	0.13	0.06	0.03
	δ rel (%)	1.73	9.94	135.24	2.99	8.12
D	**Leaded bronze**					
	mean (n=9)	76.48	0.34	0.22	8.08	14.88
analysed	σ	0.52	0.06	0.06	0.63	0.85
	CV (%)	0.68	17.26	28.55	7.83	5.74
	BCR	**80.27**	**0.15**	**0.29**	**10.10**	**9.20**
certified	δ abs	3.79	0.19	0.07	2.02	5.68
	δ rel (%)	4.72	128.38	23.35	19.98	61.76
E	**Bronze**					
	mean (n=9)	92.42	0.41	0.20	6.89	0.08
analysed	σ	0.45	0.04	0.03	0.43	0.07
	CV (%)	0.49	8.92	13.70	6.22	81.31
	BCR	**92.45**	**0.16**	**0.19**	**7.00**	**0.20**
certified	δ abs	0.02	0.25	0.01	0.11	0.12
	δ rel (%)	0.03	158.67	3.32	1.53	60.68

Generally, higher accuracy levels were noted for low lead concentrations (8% δ relative for 0.4% Pb) as opposed to higher ones (40% and 6% δ relative for 8% and 9% Pb respectively) (Table 3.3). This could be related both to the specifications of the instrument and to nature of the element which tends to precipitate in prills and it does not to mix with the rest of the alloy components (Staniaszek and Northover 1983) (Figure 3.14). Even though, there was no standard disc with a low lead content close to the 4% used here to distinguish between lead impurities and additions, on the basis of available data it could be argued that a 4% leaded copper alloy would have been overestimated by the pXRF by approximately 2% resulting in values of 6% for the lead content (Figure 3.15). Following this, objects in the pXRF sample with 6% Pb could still be classified as with lead impurities. Nevertheless, objects including lead up to 4% and 6% Pb are 234 and 245 (out of a total of 282) respectively, and even if these 4-6% Pb samples (pXRF) were included in the group with lead impurities, the patterns discuss in following chapters would not significantly change. Finally, even with the extension of lead impurity levels up to 6% for the pXRF dataset, the mean value is higher only by 0.5%, whereas the median is essentially stable with an increase of just 0.1% Pb (see Chapter 4). Finally, despite the above typical overestimation of lead by the pXRF instrument, results are presented as analysed and they have not been moderated.

Table 3.3. Summary table of certified (standard) and analysed values for lead during pXRF analyses

CRM	**Pb values (wt%)**		
(BCR-691)	**Certified**	**Mean analysed (pXRF)**	**% of cert. value**
A	7.90	10.86	137
B	0.36	0.39	108
D	9.20	14.88	162
E	0.20	0.08	40

Table 3.4. Summary table for lead impurity values according to analytical methodology

	EPMA	**pXRF**	
	Pb <4%	**Pb <4%**	**Pb <6%**
N	65	169	180
Mean	0.41	1.09	1.54
Median	0.08	0.70	0.79
Min	0.00	0.00	0.00
Max	3.25	3.99	5.97

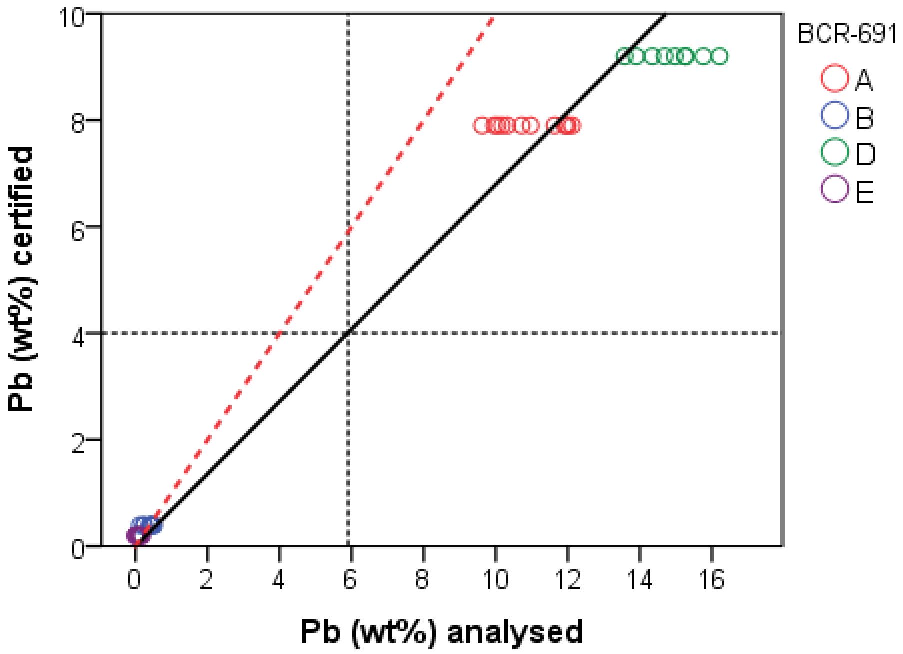


Figure 3.15. Scatterplot of Pb analysed vs certified values with fit line which provides an approximate estimation on how much higher a lead value of 4% would have been detected with the pXRF instrument (≈6%)

3.3.2 Invasive examination

Once samples were removed from the objects at the Archaeological Museum of Volos, specimen preparation and invasive analysis took place at the Wolfson Archaeological Science Laboratories at UCL Institute of Archaeology, London. Additionally to the surface analyses, invasive investigation addressed a series of questions by means of reflected light microscopy and electron microprobe analysis (EPMA) including the detection of minor/trace elements at the level of 0.01 wt% and the micro-morphological features of the samples.

3.3.2.1 Specimen preparation

Cut samples (n=70) were mounted in resin blocks which allowed their handling due to their small size, namely approximately 1-3 mm^3, and provided a clean cross section to be examined. All blocks were prepared following standard procedures. They were mounted in epoxy resin with a 4:1 resin-hardener ratio by weight which was allowed to dry for 24 hours which were then ground on a sanding sheet using silicon carbide grains to remove the top layer of resin and to prepare the surface for polishing using diamond paste down to 0.25 μm. Both grinding and polishing were undertaken manually. Before moving to a finer grade, blocks were cleaned with IMS for at least 3 minutes in an ultrasonic bath and dried thoroughly, whereas the quality of the polishing was controlled throughout this sequence under a reflected light microscope.

3.3.2.2 Qualitative: Metallography

'Metallic microstructures [hold] a nice balance between order and disorder'
(Smith 1965, p. 20)

Microscopic investigation of polished sections is a crucial step for reconstructing the life histories of metal artefacts and understanding the circumstances of their production. It allows the characterisation of metalworking techniques employed for artefacts' manufacturing and shaping, and post-depositional processes through the identification of corrosion products which result from the soil-artefact electrochemical interaction (Tylecote 1979, Scott 1991). Overall, metallography has been often described as a means to reconstruct the 'technical history' of metal artefacts and, thus, a means towards understanding the circumstances of their manufacturing (Smith 1965, Vernon 1990, in: Martin 1999, p. 115).

Metallography was conducted on all cut samples with an Olympus BX60 reflected light microscope and photo-micrographs were produced with an attached Olympus Camedia digital camera. During analysis, 25x-500x magnifications, and plain-polarized (PPL) and cross-polarized (XPL) reflected light modes were combined for the investigation of metallic grain microstructure, corrosion features, i.e. surface layers and inter-/intra-granular corrosion, as well as non-metallic phases, e.g. sulphide inclusions. Particular attention was given to the shape and size of metallic grains and dendrites, as well as to primary corrosion layers which potentially preserved original structures in the form of 'ghost-structures' (Oddy and Meeks 1982, Scott 2002) (Figure 3.16). Polished cross sections were not etched since corrosion has sufficiently outlined and revealed the metallic grain microstructure and other morphological features (see also Chapter 7).

a) b)

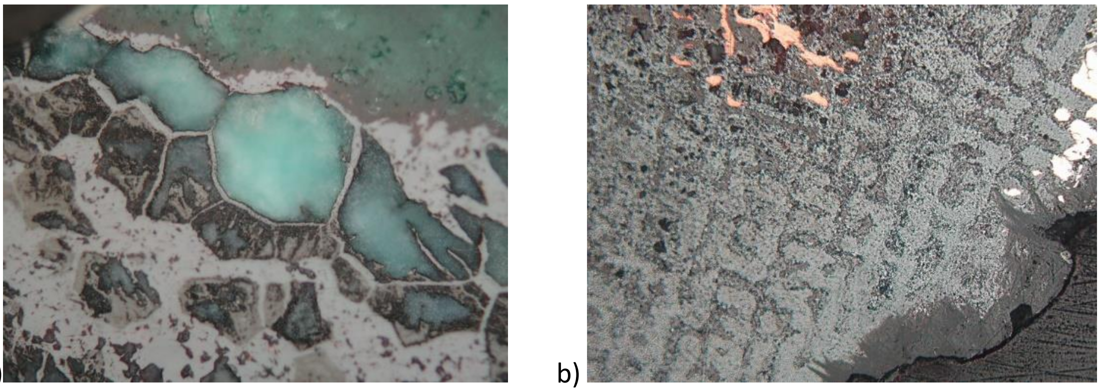


Figure 3.16. Photomicrographs of A) fibula M 1739.2 (OM, PPL, 500x, image width 300 µm) and B) ring AE 654 (OM, PPL, 200x, image width 0.5 mm) showing traces of the original granular and dendritic microstructures respectively as preserved in corrosion products

3.3.2.3 Quantitative: EPMA-WDS

Invasive compositional analysis was conducted with an EPMA-WDS (JXA-8100 Electron Probe Microanalyzer). The working principle of the microanalyzer is based on the energy that an electron emits when excited by an external source as described also for the XRF analysis (see above Chapter 3.3.1). The difference with EPMA analysis is that the electrons are excited with an electron beam which is is transformed into a thin, coherent beam which travels through a series of condenser, electrostatic lenses along a tube that control the amount of current that passes down until it hits the sample and interacts with its atoms and that it is the electron's energy wavelength that it is detected (WDS) (Goldstein *et al.* 2003, Pollard and Heron 2008).

Specimens were carbon coated (15 mm thickness, 2.25 g/cm^3 density) and analysed in full vacuum in the EPMA chamber. For each sample an average of nine area and spot measurements depending on their nature were taken at magnifications of 1000x and a working distance of 11 mm with an acceleration voltage of 20 kV, and a beam current of 50 nA. A set of 16 elements has been analysed including Se, Zn, Ag, As, Fe, Cu, O, S, Cl, Sn, Bi, Co, Sb, Ni, Mn, and Pb. Oxygen and chlorine contents were found in minimal levels as expected for analyses of uncorroded metal and, thus, are not reported here.

Precision and accuracy

A set of copper-based certified reference materials (CRMs) was regularly analysed to test the EPMA's stability, accuracy and precision, namely CRMs nos. 42.23-2, and 50.04-4 (Bureau of Analysed Samples Ltd.) (Table 3.5). The instruments' operation was found stable, whereas accuracy and precision levels were repeatedly found quite satisfactory. The analysis of standards gave a CV of 0.8% and 3.4%, and δ relative of 1.5% and 0.6% for copper in brass (42.23-2) and leaded bronze (50.04-4) respectively; equivalent values for tin in the same alloys are CV of 6.9% and 4.4%, and δ relative of 1.9% and 2.5%. For both leaded bronze and brass δ relative for lead was found 8.8% and 10.24%, and CV 32.4% and 33.4% respectively. Overall, the EPMA produced δ relative values for the trace elements in concentrations below 0.2% for both CRMs at the levels of 15-19% with medians of 11% and 15% for the brass and the leaded bronze respectively.

Table 3.5. Summary of brass and leaded bronze standards analysed with EPMA

	Zn	As	Fe	Cu	S	Sn	Bi	Sb	Ni	Mn	Pb
42.23.2 Brass											
mean (n=8)	22.47	0.19	0.35	73.23	0.05	1.66	0.02	0.39	0.18	0.02	0.63
σ	0.08	0.03	0.03	0.56	0.01	0.11	0.02	0.06	0.01	0.00	0.21
CV (%)	0.38	13.51	7.92	0.77	22.73	6.87	86.89	14.77	4.83	18.04	33.38
CRM	**22.13**	**0.17**	**0.35**	**74.36**	**0.05**	**1.63**	**0.03**	**0.36**	**0.17**	**0.02**	**0.58**
δ abs	-0.34	-0.02	0.001	1.13	-0.01	-0.03	0.01	-0.03	-0.01	0.00	-0.06
δ rel (%)	-1.53	-10.86	0.25	1.52	-14.72	-1.87	43.75	-9.23	-8.33	2.63	-10.24
50.04.4 Leaded bronze											
mean (n=10)	0.66	0.06	0.13	76.53	0.17	11.02	0.10	0.53	1.18	0.04	9.07
σ	0.05	0.02	0.01	2.60	0.05	0.49	0.05	0.04	0.05	0.01	2.94
CV (%)	8.25	42.78	4.95	3.40	27.33	4.41	43.68	8.13	3.96	28.33	32.43
CRM	**0.66**	**0.06**	**0.10**	**76.11**	**0.14**	**11.30**	**0.10**	**0.50**	**1.10**	**0.03**	**9.94**
δ abs	0.00	0.00	-0.03	-0.42	-0.03	0.28	0.00	-0.03	-0.08	-0.01	0.87
δ rel (%)	-0.55	6.67	-31.30	-0.55	-22.43	2.46	-3.30	-6.38	-7.57	-43.57	8.76

3.3.3 EPMA vs. pXRF

A group of 41 objects was selected for cross-examination with both EPMA and pXRF in order to address issues of analytical results' comparability and the possible impact of different analytical instruments' properties on the interpretation of ancient copper-based alloys (for more details see Orfanou and Rehren 2014). Selection criteria for these objects were the possibility of cutting a sample, namely fragmented objects, and, at the same time, the preservation of a substantial metal core that could be accessed by removing a thin layer of the objects' surface (Figure 3.17), while no particular distinction was made regarding the artefact typology (Table 3.6). Principal aim of this comparative analysis was to explore the degree to which surface analyses (pXRF) are representative of the original composition as determined with the EPMA away from the objects' surface and substrate, namely the layers that are most affected by surface corrosion (Figure 3.18) (See also Appendix V for detailed results tables for all elements analysed with both EPMA and pXRF, on scraped [XRF1] and intact surface [XRF2] for all 41 objects).

Table 3.6. Artefact type and frequency of the samples analysed with both EPMA and pXRF

Description	Count	Count (%)
rings	17	41
sheets	10	24
fibulae	7	17
arm bands	2	5
pins	2	5
spirals	3	7
total	41	100

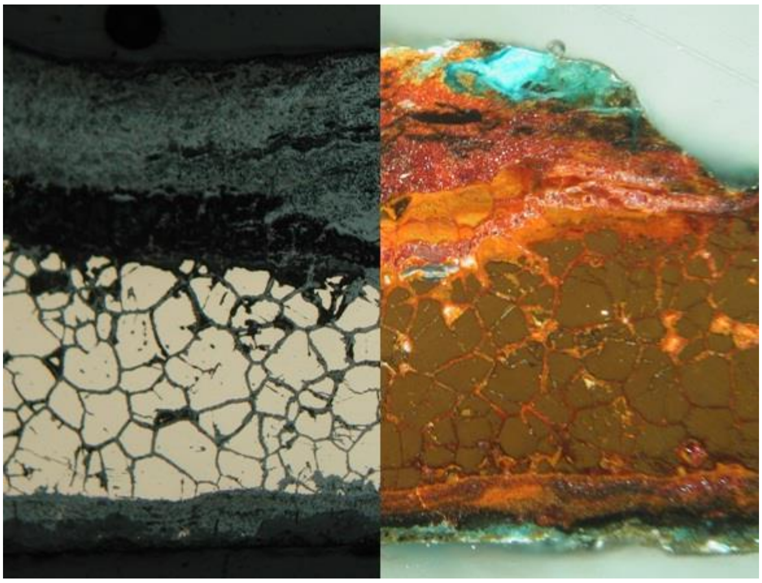


Figure 3.17. Photomicrograph of sheet AE 480; corrosion products have affected the object throughout and have highlighted metallic grains. 100x, image width 1.85mm, PPL (left) and XPL (right)

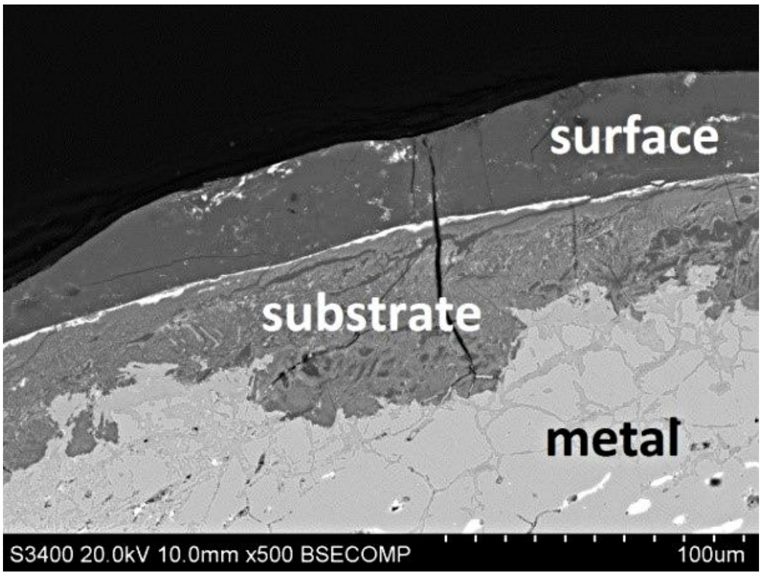


Figure 3.18. Back-scatter scanning electron image of ring AE 34 showing corrosion on the substrate and the surface (growth corrosion, patina) of the object distinguished by a thin corrosion layer (white line) which also marks the ring's original surface

Surface analyses need to be critically interpreted in order to avoid any misconceptions on the objects' overall composition and the interpretation of ancient copper-based technologies as a whole, as they produce results different to the metal core even when taking place on sound metal (Dussubieux *et al.* 2008). This could come as a result of long-term burial corrosion processes such the decuprification phenomenon (McNeil and Selwyn 2001) and various other complex degradation phenomena (Ingo, De Caro, Riccucci, Angelini, *et al.* 2006), or even from surface treatments as is often the case in precious alloys which are deliberately enriched in gold or silver (Beck *et al.* 2004) (see also below Chapter 3.4 on the corrosion effects and justification of the methodology). Moreover, it can also occur in ancient bronzes as a result of variable cooling rates and/or heat treatments, e.g. 'tin-sweat' and tinning (Scott 2012, pp. 238–240). Bronzes with tin-rich surfaces have been often found in the archaeological record such as in the Chinese and Roman metalworking traditions (Meeks 1993a, Shoukang and Tangkun 1993), whereas early examples of tin-rich bronzes are found already amongst the Celtic and Classical cultures (Meeks 1993b, p. 248). Finally, differences between the pXRF and EPMA results can be also attributed to the different detectors used, i.e. energy- and wavelength-dispersive spectrometers. These have different energy resolutions and count rate capability and, thus, different detection limits (Goldstein *et al.* 2003, p. 323) which are to be found at 0.1% and at the ppm level for the EDS and WDS respectively (Kuisma-Kursula 2000, p. 117, Donovan 2011).

Table 3.7. Characteristics of the two quantitative analytical methods and sampling strategies employed

	characteristics	advantages	disadvantages
EPMA	• WDS • invasive • sample removed by cutting • 70 samples • average of 9 measurements per sample • samples mounted in resin blocks	+ low detection limits: <0.5% for major elements and ~100ppm for trace elements (Goldstein *et al.* 2003) + metallography and examination of metalworking traces + metal core analysed, thus bypassing surface corrosion phenomena + combined multiple area and spot analyses + high spatial resolution	– fewer samples acquired due to invasive character – different degrees of deterioration from well preserved to severely corroded samples with few metal grains left – often fragmented objects could not be attributed to a specific artefact type – few samples proved completely corroded
pXRF	• EDS • surface, non-invasive • objects' surface scraped to remove corrosion patina • 212 samples • 2 measurements per sample • spot beam ~3mm	+ possibility for whole, well preserved objects to be analysed allowing the examination of a large set of objects + non-invasive: physical integrity of objects not tampered with + attribution of most samples to artefact types/categories and, in the case of fibulae, to regional workshops	– results could be affected by surface corrosion phenomena not visible to the naked eye such as enrichment or depletion of surface in certain elements including decuprification and 'tin-sweat' – only spot analyses – time consuming (300" required per analysis) – few analyses per sample

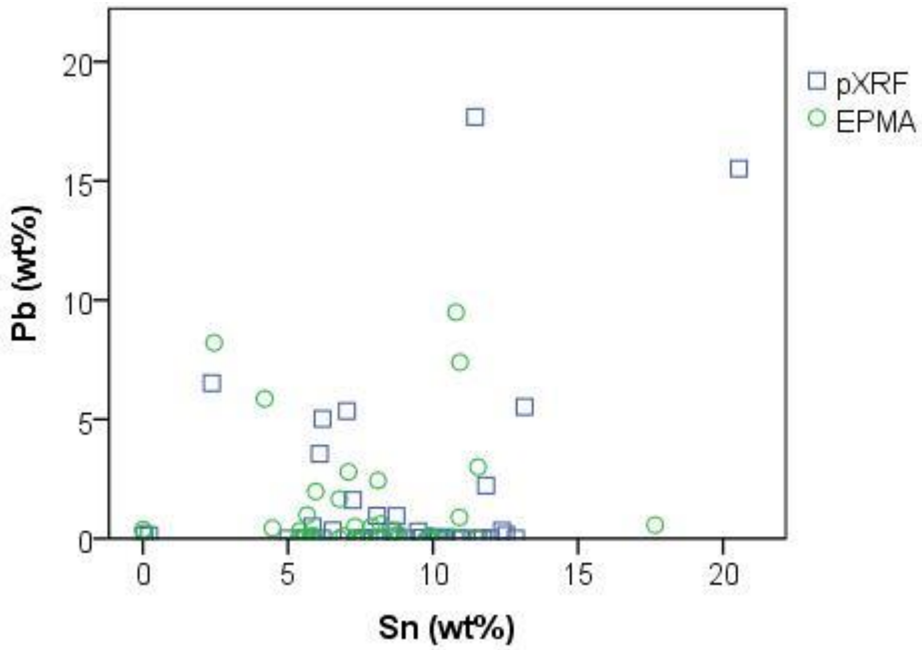


Figure 3.19. Scatterplot of tin against lead as analysed with pXRF and EPMA (n=41)

Combination of the two analytical techniques took place in order to overcome the limitations and take advantage of the benefits that each instrument comes with (Table 3.7). On the one hand, more samples and whole objects could be analysed with the pXRF faster due to the EDS detector and its non-invasive character, whereas, on the other, the EPMA provided more accurate results due it its lower detection limit, as well as it allowed the analysis of metal away from the surface and substrate layers. For instance, analysis of the large number of fibulae examined (n=119) could not have been possible only with the EPMA, since both time and sampling limitations applied.

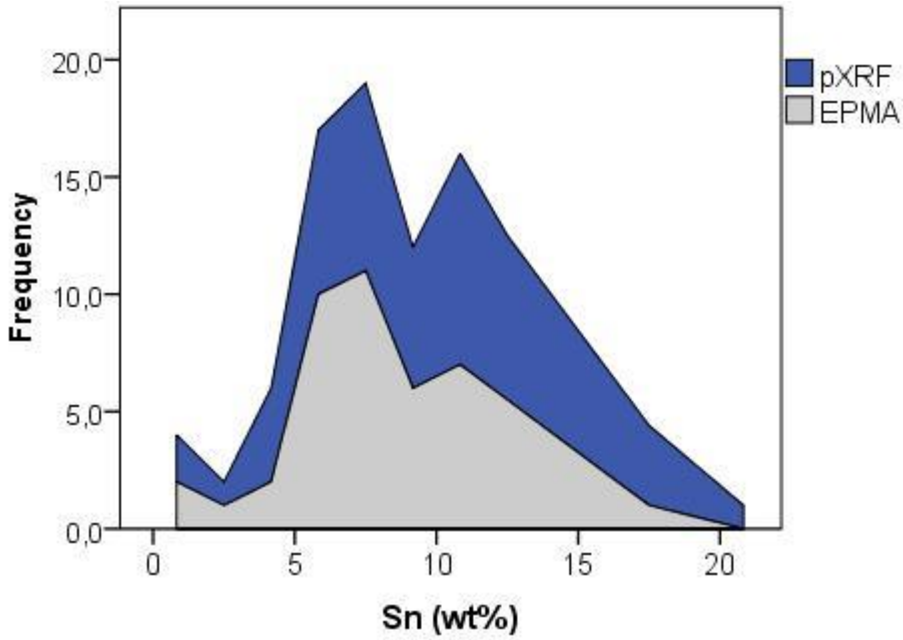


Figure 3.20. Area histogram for the tin values as produced with pXRF and EPMA (n=41) where the same distribution pattern is visible

Table 3.8. Summary table (n=41) of pXRF and EPMA results; δ abs is calculated on EPMA mean values (n/a, not applicable)

		Fe	Ni	Cu	Zn	As	Sn	Sb	Pb
pXRF	mean	1.55	0.24	86.82	0.44	0.30	8.84	0.18	1.64
	median	1.00	0.21	87.75	0.31	0.27	8.74	0.15	0.05
	min	0.27	0.09	59.99	0.12	0.00	0.06	0.00	0.00
	max	19.08	0.65	98.78	1.99	1.30	20.55	0.56	17.68
EPMA	mean	0.16	0.07	90.51	0.00	0.16	7.50	0.09	1.24
	median	0.05	0.03	91.02	0.00	0.14	7.31	0.07	0.20
	min	0.00	0.01	79.05	0.00	0.01	0.01	0.00	0.00
	max	1.13	0.45	99.40	0.00	0.64	17.66	0.52	9.49
mean	δ abs	1.39	0.17	-3.69	0.44	0.14	1.34	0.09	0.4
	δ rel (%)	869	243	-4	*n/a*	88	18	100	32
median	δ abs	0.95	0.18	-3.27	0.31	0.13	1.43	0.08	-0.15
	δ rel (%)	1900	600	-4	*n/a*	93	20	114	-75

3.3.3.1 The major elements

Examination of the samples with both techniques revealed particular element distribution patterns for each of the instruments. For the major elements, namely copper, tin (Figure 3.20) and lead similar distribution patterns were visible across the two datasets (Figure 3.19), whereas notable variations occurred in the trace element concentrations. Major elements showed greater dispersion in the pXRF dataset, whereas they revealed a similar distribution pattern for the whole sample (Figure 3.21).

Consequently, only for copper pXRF values were found lower than these produced by the EPMA with a mean relative difference of 4% (Table 3.8). Tin and lead contents as analysed with the pXRF tended to be higher than the EPMA ones by 18% and 32% (δ rel) respectively. Tin values as analysed with the pXRF varied as much as 75% or 50% respectively in comparison with the EPMA analyses, while this variation is proportionate to the tin concentrations themselves (Figure 3.23). Even though metallic areas have been analysed with the pXRF, often inter-granular corrosion products run through the whole object that could still affect surface analyses (Figure 3.17) which could have resulted in tin enriched surfaces (Scott 1985, pp. 55–56). This pattern of selective leaching of copper enhanced by long-term corrosion processes has been often observed in ancient buried bronzes (Oddy and Meeks 1982, Meeks 1986, p. 133, Ingo, De Caro, Riccucci, Angelini, *et al.* 2006, pp. 517–518).

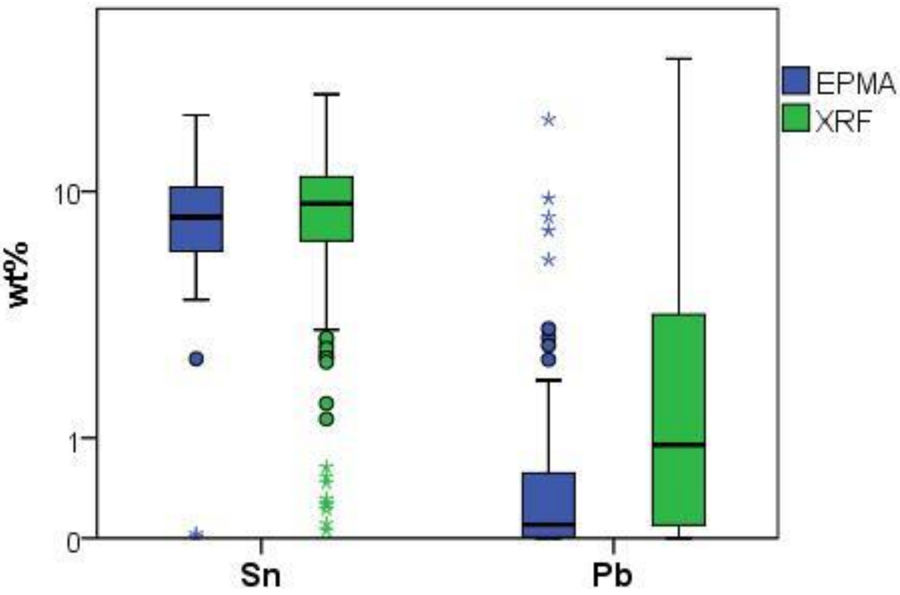


Figure 3.21. Five point boxplot for tin and lead as analysed with EPMA and pXRF showing a greater dispersion in values for the pXRF results for both elements (logarithmic scale)

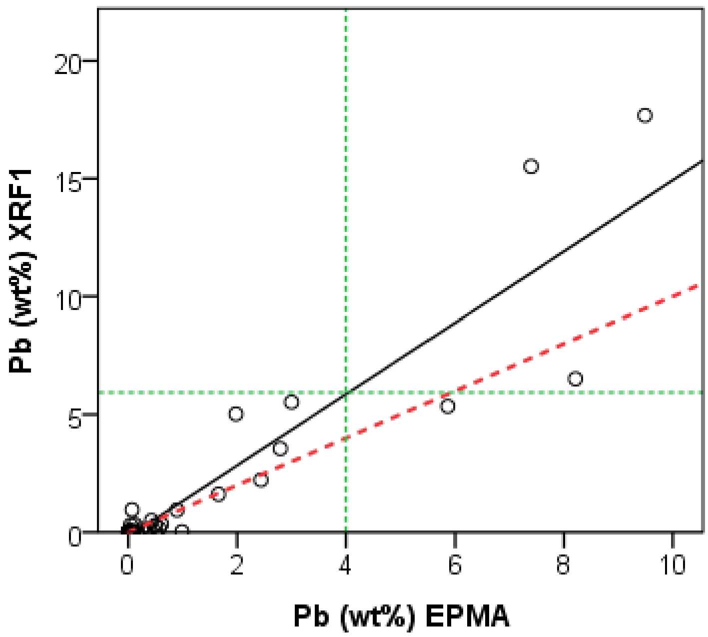
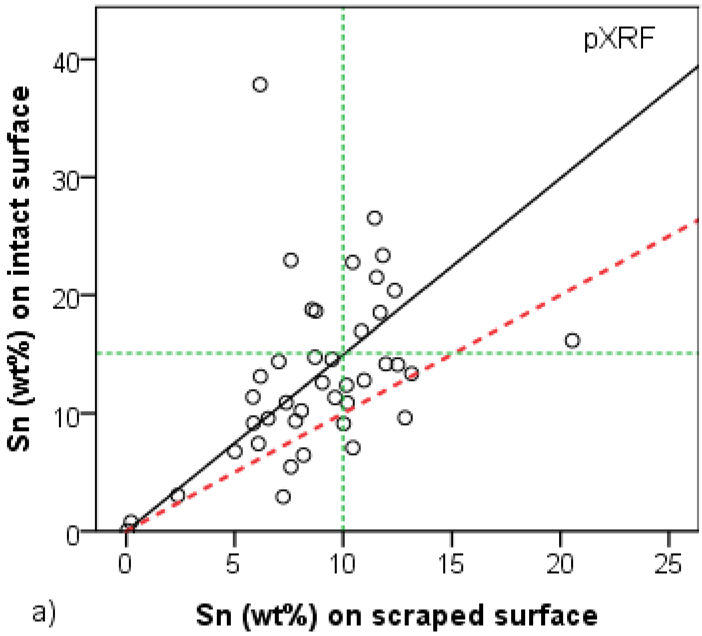


Figure 3.22. Scatterplot for lead values as analysed with EPMA against pXRF; when EPMA values are typically lower by the pXRF ones by 30%; where the trend line (black), the ideal correlation, i.e. y=x (dotted red) are visible; the dotted green lines show the degree of analytical error on the basis of the trend line

Greater variation consistently took place in the lead values for which pXRF produced lower median values than EPMA (-0.15% Pb difference for median values). This could relate to the higher detection limit of the pXRF, typically at 0.1%, which would not detect lead concentrations below that and as also noted during the CRMs' analyses (Table 3.3). Almost half of EPMA analyses (18 of 41) showed a lead content lower than or close to the detection limit of the pXRF, while EPMA lead concentrations <0.05% Pb in 14 objects, were only detected in three by the pXRF. However, when lead is detected by the pXRF, values tend to be higher than the EPMA ones (Figure 3.22). Finally, 0.05% Pb as measured with the EPMA seems to be the detection limit of the pXRF which largely did not detect lead concentrations below this level, whereas for values >0.05% Pb pXRF values are on average higher than the EPMA ones (Figure 3.21).



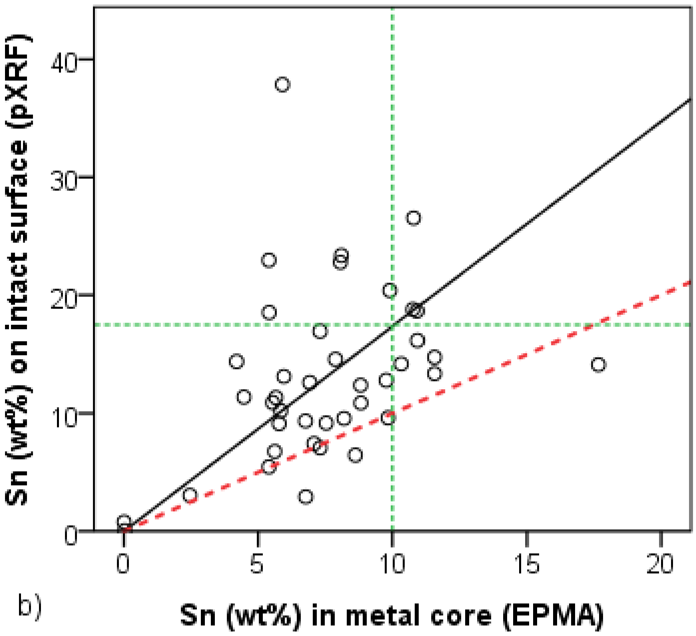


Figure 3.23. Scatterplots for the analyses of tin by the EPMA and the pXRF (on intact and scraped surface) where the trend line (black), the ideal correlation, i.e. y=x (dotted red) are visible; the dotted green lines show the degree of analytical error on the basis of the trend line

3.3.3.2 Minor and trace elements

Larger variation took place in the minor and trace element concentrations as measured with the two detectors. Surface examination of the objects, even on areas free of corrosion products, renders the limitation of possible alterations in the metal. This could be a result of both electrochemical corrosion processes on the metal, as well as the interaction of the objects with the soil environment which is rich in certain elements, such as iron, manganese and zinc, present naturally and also potentially enhanced by human activity (Jenkins 1989).

Iron pXRF values, as in the case of tin, tend to be significantly higher than EPMA ones. Iron typically occurs in ancient bronzes at impurity levels. Moreover, iron concentrations in the form of iron oxide tend to increase on the objects' surface due to corrosion processes and its presence in soil environments as it is the fourth most abundant element in the Earth's crust (Jenkins 1989, p. 59, Ingo, De Caro, Riccucci, Angelini, *et al.* 2006, p. 513). Nonetheless, certain patterns for the iron concentration in the sample present in the EPMA dataset are further confirmed by the pXRF such as, for instance, a negative correlation between iron and lead values (see below Figure 5.17).

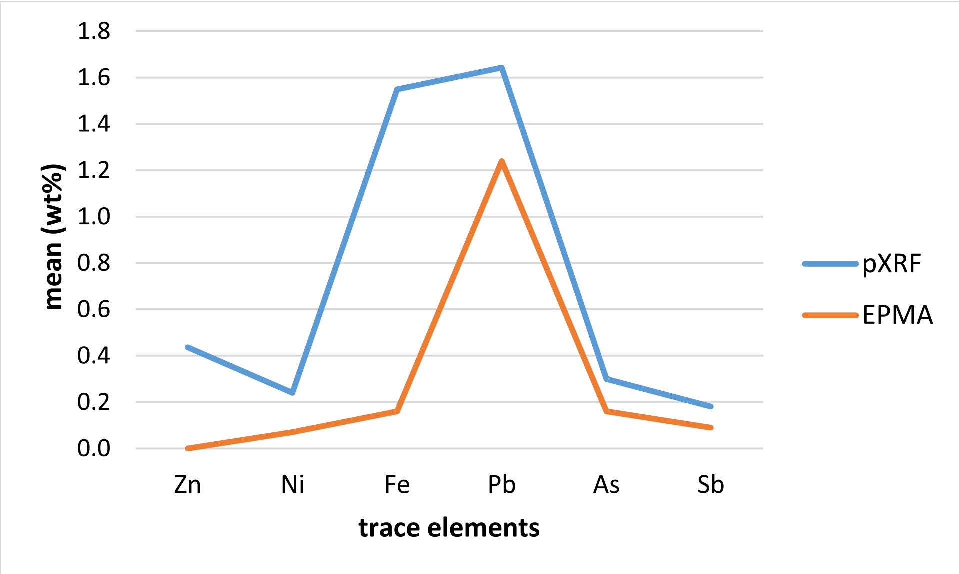


Figure 3.24. Line graph showing mean concentrations for the trace elements in the pXRF and EPMA datasets

Values for arsenic, nickel, and antimony also tend to increase in the pXRF dataset in comparison with the EPMA (Figure 3.23). Furthermore, although no zinc was found with the EPMA (zinc content could be below the detection limit of the WDS), pXRF analyses detected traces of zinc just below 0.5% in most samples, whereas in fewer samples higher zinc levels up to 2% (pXRF) were found. As in the case of iron, zinc too could be the result of corrosion and environmental enrichment since it is a relatively mobile element present in most soils (Jenkins 1989, p. 57). However, on the basis of EPMA results the assemblage has to be considered zinc-free and pXRF data have to be treated critically. Finally, unlike other trace elements, arsenic and antimony pXRF concentrations are quite close to the EPMA values.

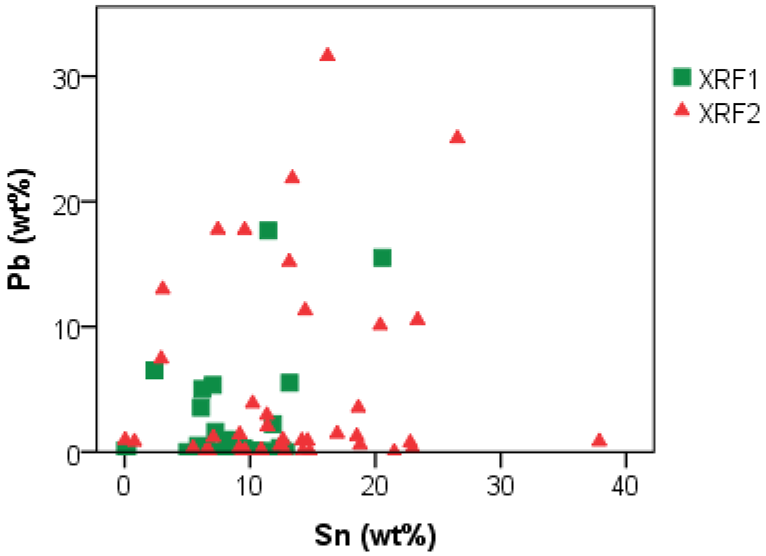


Figure 3.25. Scatterplot of tin against lead for the group of 41 objects as analysed on their intact (XRF2) and scrapped (XRF1) surfaces. Higher values for both elements in XRF2 were observed for the vast majority of the objects

In conclusion, interpretation of surface pXRF results needs to take into consideration possible surface enrichment of the objects during long-term burial as well as the different detectors' specifications. The detection limit of the pXRF has to be considered particularly when dealing with trace elements. Phenomena of reverse segregation and preferential depletion either of copper or tin in ancient bronzes have also to be addressed since they can immediately affect surface pXRF measurements (Scott 1985, Meeks 1986, p. 137). By using a pXRF it is safe to address questions regarding the nature of the main components present in the copper-based, but a more careful reception of pXRF results should be followed for the trace elements (Figure 3.20). Finally, despite that levels may vary for the major elements, trends and patterns in the results typically are in agreement across the two datasets while, elevated trace element concentrations of surface pXRF need to be addressed critically (Figure 3.23).

3.4 The effects of corrosion on copper-based artefacts during long-term burial

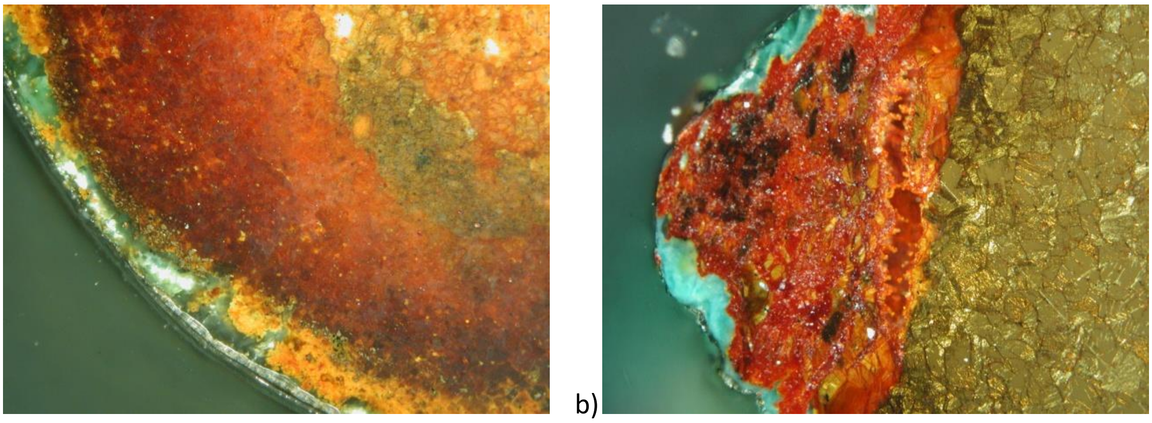
All archaeological copper-based objects undergo the effects of corrosion processes during long-term burial and the assemblage from the Enodia sanctuary is not an exception to this. These are the result of the electrochemical interaction between metal and soil/environmental conditions. Some of these corrosion phenomena occur often in ancient copper-based artefacts, while others are observed more rarely. Identification of corrosion phenomena is key to the post-excavation preservation of ancient metal objects and in understanding their full object biographies or even verifying their authenticity (e.g. Lewin 1972, Robbiola and Portier 2006), and is of great importance to both conservators and archaeologists (e.g. McNeil and Selwyn 2001, Bosi *et al.* 2002, Selwyn 2004). The investigation of the nature and behaviour of corrosion products on ancient copper-based artefacts has a long history from as early as the early 19^{th} century as illustrated by the work of Davy (1826) up to recent and ongoing research (e.g. He *et al.* 2011). Here, the most common corrosion phenomena on ancient bronzes which they can potentially affect the interpretation of analytical results are reviewed as documented by conservators and archaeometallurgists. This overview is particularly important in the consideration of the pXRF results from objects' scrapped surfaces which they could still be affected by corrosion to variable degrees (see also Figure 3.17 where inter-granular corrosion has spread throughout the sample).

3.4.1 Common corrosion phenomena in archaeological copper and its alloys

3.4.1.1 Patinas, the decuprification phenomenon and surface enrichment

The term patina corresponds to the formation of growth corrosion layers on the surface of the metal objects. The formation of patinas largely depends on the objects' composition and microstructure, as well as the soil chemistry, and it is strongly associated with the decuprification phenomenon. The latter is a 'global phenomenon of copper corrosion' which refers to the selective dissolution of copper from copper-based alloys from the objects' surface and substrate due to the alloys' internal oxidation (Robbiola and Portier 2006, pp. 1, 4). As a result, tin-rich corrosion layers are often observed in patinas of ancient bronzes (see also below this chapter on tin-rich surfaces). In most buried bronzes the enrichment of tin in the outer corrosion layers is further enhanced by the formation of cassiterite (SnO_2) or hydrated tin oxides (Scott 2002). The above corrosion mechanism often leads to higher tin detected during surface analysis of copper-alloy objects than would have been present in the original copper-based alloys.

Although Scott (2002, p. 11) uses the term patina to describe a thin, smooth layer of cuprite and malachite that follows the original shape of the object, others use it to describe a larger range of surface corrosion phenomena. Robbiola et al. (1998) employed a phenomenological model in order to explain the formation of growth corrosion on the basis of the decuprification phenomenon. They recognized two types of patina, namely Types I and II (Figure 3.26). Patina Type I is used to describe 'even' surfaces with a two-layer passivating deposit which also coincides with Scott's term for patina. The presence of tin stimulates the formation of such passive, i.e. protective, layers of corrosion, whereas the presence of lead in small concentrations does not seem to modify this behaviour (Soto *et al.* 1983, Gerwin *et al.* 1998, Robbiola, Pereira, *et al.* 1998, McNeil and Selwyn 2001). Type II patina is used to describe coarse surfaces and corresponds to more severe corrosion attacks. It is modelled by a three-layer structure characterized by the presence of cuprous oxide and by an increase in the chloride content (Figure 3.26b). The three distinct layers consist of a) an external altered zone of copper chlorides, b) a layer of cuprite and c) and internal layer of yellow-orange-brown colour characterized by lower copper and relatively higher amounts of tin than in the uncorroded alloy, associated with soil elements, mainly oxygen and chloride (Robbiola, Blengino, *et al.* 1998). While Type I, also known as 'noble patina', is chemically stable and passively protects bronze objects (see also Bernard and Joiret 2009), Type II is harmful and destructive due to the presence of chlorides (Gerwin *et al.* 1998). In the Enodia assemblage both types of patina have been detected.



a) b)

Figure 3.26. Photomicrographs of (A) pin Burial 2.15 and (B) of fibula T 59.10 from the Toumba cemetery at Lefkandi, Greece, showing the two-layer Type I and the three-layer Type II patinas respectively. In (B) the green layer consists of copper chlorides and copper silicate, and is followed by a red layer of cuprite and, in contact with the metallic grains, an orange layer of copper and tin oxides and chlorides (corrosion products have been identified with SEM-EDS). OM, 200x, image length 0.85 mm, XPL (after Orfanou 2009, Appendix D)

Tin-rich surfaces may also occur due to a number of reasons and not only the decuprification phenomenon or the selective corrosion of copper. For example, deliberate tinning or accidental tin-sweat may result in high tin surfaces of copper-based alloys (Meeks 1986, Giumlia-Mair 2005a). Surface tinning could be achieved by the application of heated tin on the copper-based objects' surface which would result in the partial dissolution of tin into the copper alloy (dip or wipe tinning), by cassiterite (tin oxide, SnO_2) reduction, electrochemical tinning, mercury amalgam tinning and electrolytic tinning (for more details see Oddy and Bimson 1985, Meeks 1986, Giumlia-Mair 2005a). Even though not all these techniques would have been used simultaneously in antiquity and electrolytic tinning was only practiced extensively from the late 1920s onwards (Hedges 1960, in Meeks 1986, p. 135), they illustrate the possible alternative causes for the formation of high tin surfaces in archaeological copper-based alloys. Corrosion of tinned surfaces typically forms cassiterite mixed with malachite and cuprite as a result of the interaction between the tin layer and the copper alloy. Furthermore, in the presence of lead, tin would combine with the lead globules and result in dark spots on the object's surface (Giumlia-Mair 2005a, p. 361). Lead is also easily dissolved in the soil environment, resulting in strong relative enrichment of corrosion products in lead compounds (Robbiola, Pereira, *et al.* 1998).

The presence of additional elements or impurities to copper such sulphur or silver (e.g. Beck *et al.* 2004), etc. can have an impact on the nature of corrosion products formed, as well as on the rate of the deterioration processes. For instance, tin has most often been found to act as a corrosion resistant agent in ancient copper as also observed by Bernard and Joiret (2009, p. 5205) who found that 'copper compounds are found to be sensitive to oxidation or reduction but the presence of "amorphous" SnO_2 in the patina of bronze objects has had a beneficial effect'.

Bronze disease is another type of surface corrosion often observed on archaeological bronzes. It has been described by Scott (1990, p. 193) as a 'product of most serious concern' for the preservation of archaeological bronzes due to the presence of chlorides. Bronze disease is manifested in light green growth spots/patches with a powdery texture which may disfigure the original surface, and is oxygen and moisture dependent (Scott 1990). The transformation of cuprous chloride to basic copper chlorides that takes place in ancient metals during long-term burial, is accompanied by the damage of the original corrosion layer which is also the one to preserve the original surface of the object (Wang *et al.* 2006).

3.4.1.2 Inter- and intra-granular/dendritic corrosion

In addition to corrosion precipitating on and affecting the surface layers of the objects, degradation of buried metals often takes place around and within metallic grains, namely inter- and intra-granular/dendritic corrosion or localised corrosion (McNeil and Selwyn 2001, p. 609). This type of corrosion attach as with patina (see above) has been observed in variable degrees in the vast majority of the sample examined (see also Metallographic Summary, Appendix IV). Only in eight samples no inter- or intra-granular/dendritic corrosion was observed which all tended to be from both very well preserved and completely corroded objects.

3.4.1.3 'Ghost' structures

Another common corrosion phenomenon is the pseudomorphic replacement of metallic features by corrosion products, also often described as benign corrosion and associated with Type 1 patinas (Oddy and Meeks 1982, Robbiola and Portier 2006, p. 5). These structure can replace both dendrites and grains (see also Figure 3.16 above). In the Enodia assemblage often the replacement of metallic grain microstructure by corrosion products was observed. This allowed for the exploration of the metalworking techniques employed even in samples otherwise corroded.

3.4.1.4 Re-deposited Cu crystals

Cuprous chloride can be thoroughly reduced to pure copper if reduction time interval is sufficiently prolonged, resulting in pure copper crystals being re-deposited to the substrate. The formation of copper inclusions in ancient copper is slow kinetic process which is also heavily dependent on environmental conditions, while several explanations have been put forward about this mechanism (Bosi *et al.* 2002, pp. 4285–6). Bosi et al. (2002, pp. 4290–1) have noted that unalloyed copper inclusions tend to precipitate in the metal core and in proximity with copper sulphides rather than in the object's surface or substrate. The inclusions size and shape vary greatly due to their different formation processes which have lead Bosi et al. to categorise them in three distinct groups, namely types A to C with B and C types to have possibly formed prior to deposition in soil (Bosi *et al.* 2002, pp. 4292–7).

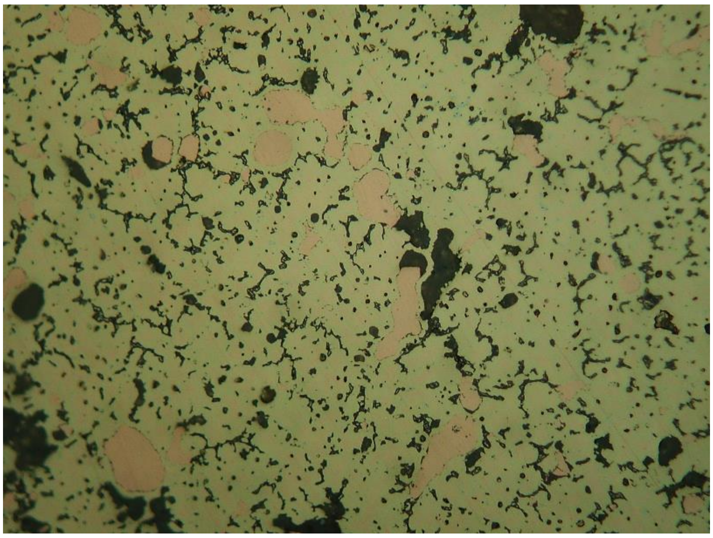


Figure 3.27. Photomicrograh of ring AE 507 showing pure copper globules segregating between dendrites and coring. PPL, 500x, image width 300 µm

This corrosion process can also assist in the conservation of the corroded objects by removing the harmful copper chloride and transforming it into pure copper. Ancient metals have the advantage of long-term corrosion processes and, thus, the re-precipitation of copper crystals is a corrosion phenomenon often observed. Meanwhile, replication of the phenomenon in the laboratory is difficult due to time constraints (Bosi *et al.* 2002, Wang *et al.* 2006). Re-deposited copper crystals in the bronzes from Enodia have been observed in just a handful or samples such as ring AE 607 with a dendritic structure (Figure 3.27). However, in the case of AE 507 these should not be taken necessarily as the result of corrosion. They could have been caused during the metal's cooling as also suggested by coring also observed in the sample.

3.4.1.5 The effect of alloying elements in copper

3.4.1.6 Other corrosion phenomena

Copper sulphide corrosion products are a common corrosion feature of objects from shipwrecks and they are linked to underwater, anaerobic conditions, while exposure to atmospheric conditions has also been suggested as the trigger to sulphidation (Soto *et al.* 1983, p. 249) (Figure 3.28). They also form in coastal waters were decaying animal and vegetable matter provide a source for sulphur (Oddy and Meeks 1982). Copper sulphide products are largely absent from the samples examined from the Enodia sanctuary. Furthermore, the presence of phosphorus in copper-based alloys corrosion products has been associated with the presence of bone fragments in the corrosive environment in the absence of any iron artefacts (Ingo, De Caro, Riccucci, and Khosroff 2006). Finally, a gold-like thick layer of chalcopyrite has also been observed by Ingo et al. (2006) on ancient tin bronzes.

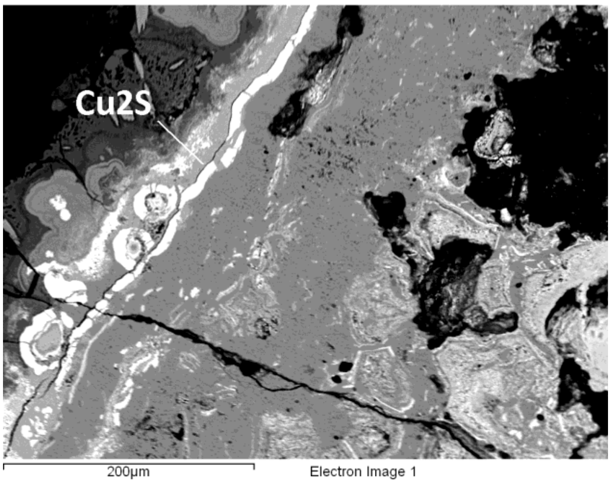


Figure 3.28. BSE image of grater T Pyre 13.8 from the Toumba cemetery at Lefkandi showing the copper sulphide layer that is formed close to the surface, 250x (after Orfanou 2009, Appendix D)

3.4.2 Surface analysis of archaeological copper-based objects and the debate around portable X-ray fluorescence

Surface analysis of ancient copper-based objects has long been practiced as part of the archaeological practice (Giumlia-Mair 2005b). The non-destructive character of surface analysis along with the availability of the relatively low-cost, small size handheld and portable XRF instruments in archaeological science and conservation laboratories worldwide have intensified in recent decades the metal objects' surface examination. Some handheld XRF instruments, for instance, weight just a couple of kilograms which further facilitates their transportation. This ease of access to this technique and the lack of a variety of non-destructive analytical techniques (Shackley 2011a, p. 4) have probed its use by a wide range of researchers active in the study of past material culture and with variable degrees of training into the workings of portable XRF. For a review of X-ray fluorescence spectroscopy in archaeology see Shackley (2011b, pp. 7–8).

Consequently, a long-standing discussion and debate around the limitations and potentials of surface pXRF analyses have been and are currently taking place. The discussion amongst archaeologists, scientists, curators and conservators has involved the examination of a range of inorganic materials including copper-based alloys. In fact and as argued by Frahm and Doonan (2013, p. 1425) 'few other recent instrumental developments have generated such debate' (for example, see Frahm (2013a, 2013b) and Speakman and Shackley (2013) for a discussion about the use of pXRF in the sourcing of obsidian]. Meanwhile, whole conference sessions have been dedicated to this topic such as the session organised by Tykot and Vianello (2015) on the 'scientific analysis of archaeological objects in museums: modern technologies and limitations of the collections'. The session largely facilitated a discussion around the limitations and potentials of pXRF instruments used to examine museum collections. There seemed to be an agreement that, on the one hand, the non-destructive nature of the instrument is invaluable for the nature of archaeological research, and that, on the other, researchers need to present their methodologies in detail. This stance in addressing the uncritical use of surface pXRF analysis has been adopted by a number of publications throughout the years (e.g. Ferretti and Moioli 1998 on large bronze sculptures, Dussubieux *et al.* 2005 for use in fine arts, Karydas 2007 on metal artefacts from museum collections, Forster *et al.* 2011 on ceramics) and also the one taken by the present study.

3.4.2.1 XRF analyses of copper-based alloys

Regarding copper-based alloys a number of scholars have been too conducting surface pXRF analyses (e.g. Karydas 2007, Legnaioli *et al.* 2007, Cesareo *et al.* 2011, Karydas and Asderaki-Tzoumerkioti 2011, Martinón-Torres *et al.* 2012, Charalambous *et al.* 2014, Cockrell *et al.* 2014). Such studies have successfully addressed the issues on access to artefacts from museum collections (e.g. Tite 2002, Tite *et al.* 2002, Henderson and Manti 2008), as opposed to slag fragments or metallurgical ceramics for which typically sampling is more accessible. Similarly a number of scholars has been engaged in a discussion on the limitations around the interpretation of these results and the potentials of portable equipment on the objects' surface (Dussubieux *et al.* 2005, Angelini *et al.* 2006, Gianoncelli and Kourousias 2007, Goodale *et al.* 2012, Shugar and Mass 2012, Frahm and Doonan 2013, Shugar 2013).

Furthermore, several researchers over the years have published comparative analysis of pXRF and invasive analytical techniques in order to test the degree to which XRF results reflect the objects' original compositions (e.g. Carter *et al.* 1983, Lutz and Pernicka 1996, Haruyama *et al.* 1999, Orfanou and Rehren 2014). Similar studies have been also conducted on metals' corrosion products (Ingo *et al.*

2004, Ingo, Balbi, De Caro, Fragalà, *et al.* 2006). These studies illustrate in detail the issues surrounding this topic. Most conclude that surface XRF results can be useful in the non-destructive examination of metal artefacts but they also need to be treated carefully. For example, Lutz and Pernicka (1996, pp. 318–322) have argued that it is possible to obtain reliable data of the surface composition of objects non-destructively with EDXRF and showed that these surface data should be used for the 'screening of metals to obtain general information on alloy compositions' which may then lead to more detailed examination. They also suggested that more accurate results should be obtained during the analysis of drilled samples from the metal cores as also performed more recently by Gitler and Ponting (2006, p. 321) and Gitler *et al.* (2008, p. 14). Nonetheless and despite the decades of performing surface XRF analysis in archaeological laboratories the need for the critical evaluation of the produced results is still being repeatedly emphasized by scholars (see also references above).

3.4.2.2 On the reliability of XRF

Early on, researchers have dealt with issues of reliability, sensitivity and reproducibility of XRF data. For instance, Hall (1960) has argued that XRF analysis is not suitable for all projects irrespectively. Meanwhile, Carter (1977, p. 72) has reported good reproducibility of results for XRF on the bases of several repeated analyses on Roman coins. And, Ferretti *et al.* (1997, p. 244) have concluded that the non-destructive character of XRF does not necessarily 'preclude the possibility of detecting, though not measuring, small compositional differences'. More recent papers have explored further the potentials of XRF instruments (e.g. Shugar 2013).

The methodological issues that need to be addressed during surface XRF analysis are related to the instrument's detection limit and stability, penetration depth of the X-ray beam which also depends on the elements present, size of X-ray beam, analysis time, kV range available, the different modes available for the analysis of the different materials, for example most pXRF instruments have an 'alloy mode' for the analysis of metals, as well as the software used for the processing of the generated data. In the past, pXRF results have been occasionally considered qualitative or semi-quantitative at best (Dussubieux *et al.* 2005, p. 767). In addition, surface analysis of metals entail the risk of detecting elements induced to the metal from the burial environment (Giumlia-Mair 2005b, p. 36).

3.4.3 The implications for the study of the Enodia assemblage

The above overview is a brief account of some of the most commonly observed corrosion effects on archaeological bronzes and issues encountered in the surface examination of metal objects. Emphasis has been put in the effects occurring during long-term burial in soil environments and the surface examination of metal artefact by means of portable XRF which are also the circumstances that correspond to the examined sample. For instance, the corrosion effects that have been most often observed in the Enodia sample include the presence of surface patinas and tin-rich corrosion layers close to the object's surface, as well as inter- and intra-granular/dendritic corrosion. Potentially, these corrosion effects could have had an impact on the quantitative results obtained. Hence, the methodological protocol employed for the surface compositional examination of the Enodia sample (see also above Chapter 3.3) has been designed in order to address such issues of surface depletion or enrichment in certain elements.

In more detail, limitations may potentially apply to the pXRF analysis of the objects since it was not possible to examine microscopically the preservation state of the analysed spot. In order to address this issue, firstly the objects' surfaces have been scraped (see also Chapter 3.3.1) and any patina or corroded substrate layers have been mechanically removed. This allowed the exposure of the uncorroded metal areas visible with a bright metallic colour which have then been examined with spot pXRF analysis and has been used in the past (e.g. Carter 1977, Lutz and Pernicka 1996). Secondly, taking into consideration that certain corrosion products may not be visible with the naked eye and that traces of certain oxides/chlorides may still be present in the analysed areas, as well as issues of ancient metals heterogeneity (Caley 1964, Charles 1973, Dussubieux *et al.* 2008) several spots have been analysed per object with two spot analyses minimum. For instance, this methodology of multiple spot analysis has been adopted by Ferretti *et al.* (1997) in the examination of a Greek bronze statue, the Capitoline Horse, Thirdly, the pXRF from the scraped surfaces of forty-one objects were compared to EPMA results on the sound, corrosion-free metal cores of the same objects in order to test the reliability of the former. These results (also discussed above in Chapter 3.3.4) showed that tin and lead tend to be overestimated by an average of 20-30% of the EPMA value, while the overestimation was higher for the lead. This has been attributed not only to the presence of corrosion products but also to the pXRF's specifications since lead has been typically overestimated during the analyses of certified reference materials (CRMs) too, not only archaeological objects (see also Table 3.2 & Figure 3.15). In order to account for this, lead values as measured with the pXRF have been renormalised on the basis of the CRMs' analyses.

Finally, in order to prove the quantitative character of the pXRF results produced here they have been compared with the EPMA dataset which is taken as more reliable due to the instrument's sensitivity, as well as due to the fact that metal cores as opposed to surface layers have been examined (see Chapter 3.3.3 and below 3.5.2).

3.5 Limitations of the study

During the study, certain limitations of the assemblage itself, the analytical instruments' properties and the published data that have been incorporated in the study (see Chapter 2) applied. These are addressed below in order to shed light on the interpretation of results discussed in following chapters.

3.5.1 Dating and provenance of material

Firstly, the dating of the sample has been problematic due to its recovery in mixed deposits and the long-lived character of many artefact types whose over several generations was not uncommon. This has been addressed by relying on established typologies such as for the fibulae and the group of the Macedonian bronzes or the bird pendants, but also on contemporary burial or better dated sanctuary contexts (for more details see also Appendix I). Nonetheless, the above approach has not been sufficient in dating a large part of the sample which has been loosely grouped within large time spans often a century long. For example, many objects have been dated to the 8th century BC without being possible to chronologically characterise them more closely. Consequently, the material used in the present study has not been found suitable enough to promote a detailed diachronic approach at the present state of research that would trace changes in the metallurgical production from the Protogeometric down to the Archaic period.

Further limitations applied at the actual production sites of the objects recovered at Pherae and their typology. On the one hand, typologies have been traditionally used to identify different regional workshops, while, on the other, the latter have not been necessarily related to specific production sites as certain typologies could have been produced and imitated over a broader geographical region. Even though there is evidence to support the local production of copper-based objects in Thessaly and ancient Pherae it is difficult to identify, at least macroscopically, which of the objects in the sample have been actually locally manufactured. Nonetheless, certain typological groupings have been incorporated in the discussion of the results in an attempt to shed more light on the circumstances of these objects' production and, in fact, to explore the relationship between their typological and technological attributes. Finally, any conclusions drawn from considerations of typology have always acknowledged the fact that the actual place of production is far from certain.

3.5.2 Results comparability

The use of two analytical techniques (see also above Chapter 3.4.3), namely pXRF and EPMA-WDS, even though it allowed the investigation of a much larger sample due to the pXRF's non-invasive character, posed additional questions of results comparability. The issue of metals' heterogeneity and the presence of surface corrosion features along with surface analysis have been often discussed by scholars (see also above Chapter 3.4.2 & 3.4.3). Such an approach was necessary as it allowed for a much larger sample to be investigated due to the non-invasive character of the pXRF. In order to overcome the above, characteristics of the two techniques have been considered in detail, as well as they have been compared and contrasted to each other in order to reveal any particularities of the two instruments and how these have affected the quality of the results (see above Chapter 3.3.3). In addition, at the discussion of the results (Chapters 4-8), data produced by both techniques have been combined only for the major elements, namely copper, tin and lead (>4% Pb), whereas any discussion of the trace elements has taken into consideration only the EPMA dataset due to the instrument's greater sensitivity and lower minimum detection limit. Moreover, in Chapter 8 where the results from Pherae are compared to the published Early Iron Age datasets, both tin and lead values as analysed with the pXRF have been moderated on the basis of the findings of the EPMA-pXRF comparison. Lastly, the use of different techniques and protocols during the aforementioned studies has raised additional concerns whose evaluation stretches beyond the possibilities of the present study as the exact circumstances of the different analyses are not known in detail. At any rate, their synthesis in Chapter 8 and any interpretations put forward considered the above. For example, more emphasis has been put on patterns or correlations between the different elements within the respective datasets rather than on the actual weight percent results or on a comparison across datasets.

Overall, conclusions drawn from the scientific examination of the Pheraean assemblage and the discussion of the published Early Iron Age assemblages have acknowledged, addressed and where possible resolved any issues relating to instrument comparability and material the provenancing and dating.

Chapter 4. Alloying copper in EIA Greece: the evidence from Thessaly

Quantitative examination of the Pheraean sample revealed aspects of the coper-based artefacts production which relate both to the individuals involved intentional choices and to accidental events taking place during the manufacturing process. For example, the former may include the smiths' decision making over the alloying of copper, while the latter may relate to characteristic trace element fingerprints resulting from the use of characteristic ores (for a discussion of the later see Chapter 5). Below, evidence of the above is discussed focusing on the major elements, namely copper, tin and lead, and zinc for a small group of samples in order to reveal patterns of active alloying of copper during the Early Iron Age as recovered from the Enodia sanctuary.

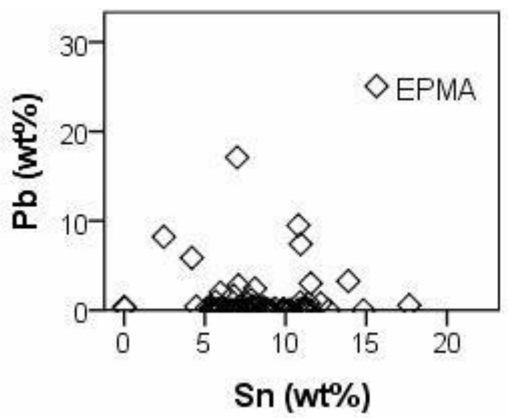
Results produced by both analytical techniques showed overall comparable mean and standard deviation values, and distribution patterns for the major elements (Table 4.1, Figure 4.1). Higher tin and lead values typically found in the pXRF dataset were expected due to methodological concerns (see Chapter 3.3.3 & 3.4) and have been taken into consideration in the interpretation of results. Thus, for the major elements' concentrations, namely copper, tin (>1% Sn) and lead (>4% Pb), pXRF and EPMA datasets have been combined, whereas trace element concentrations have been dealt separately. Meanwhile, discussion below also acknowledges the different size samples for the different datasets. Finally, all results are presented in weight percent (wt%).

Table 4.1. Summary table for copper, tin and lead contents according to analytical method (EPMA, pXRF)

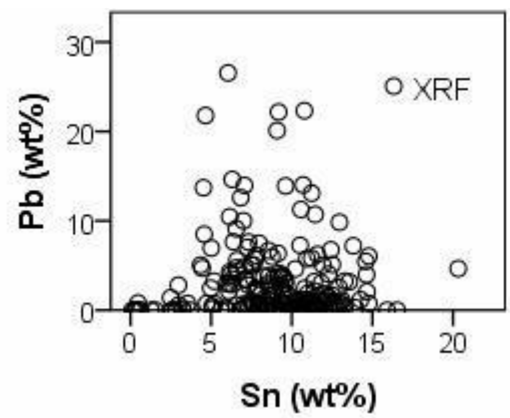
	EPMA (N=70)		**pXRF (N=212)**		**all analyses (N=282)**	
	mean (wt%)	St.Dev. (%)	mean (wt%)	St.Dev. (%)	mean (wt%)	St.Dev. (%)
Cu	89.72	4.35	86.18	5.54	**87.06**	5.48
Sn	8.37	3.03	8.84	3.39	**8.72**	3.31
Pb	1.06	2.71	3.05	4.45	**2.55**	4.17

4.1 Major elements: the alloying agents

Quantitative analysis of the entire sample (n=282, pXRF and EPMA) confirmed that all objects are copper-based. Very few pure copper objects are present, whereas the vast majority of the assemblage consists of copper-tin-lead alloys. Few samples with arsenic or antimony concentrations just above 1% or a group of zinc-rich samples have to be taken as naturally occurring (see below 4.2.4).



a)



b)

Figure 4.1. Scatterplots of tin against lead for A) EPMA (n=70) and B) XRF (n=212) analyses showing a similar pattern

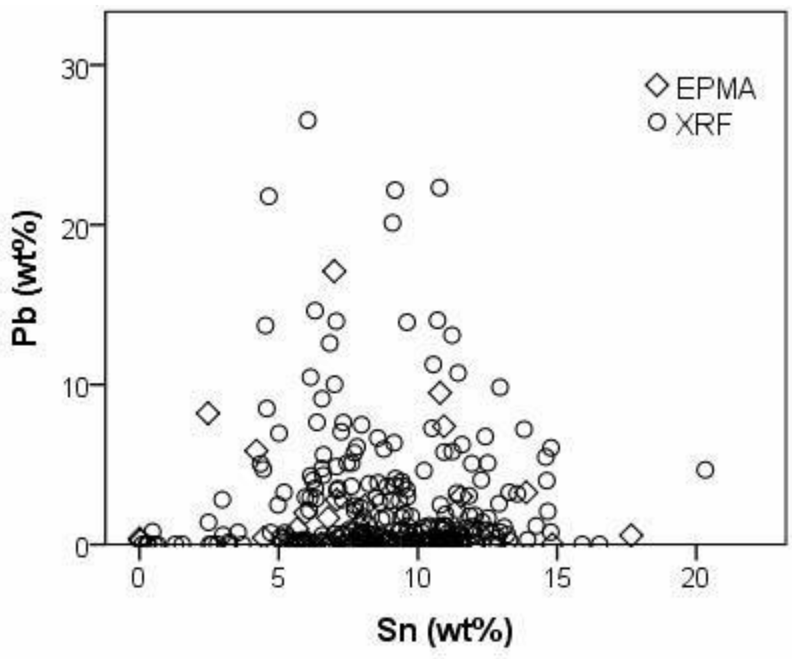
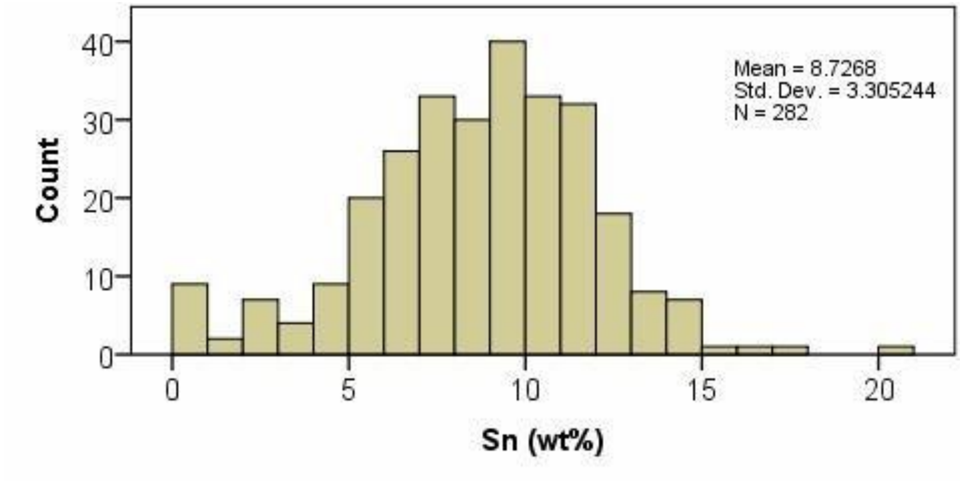
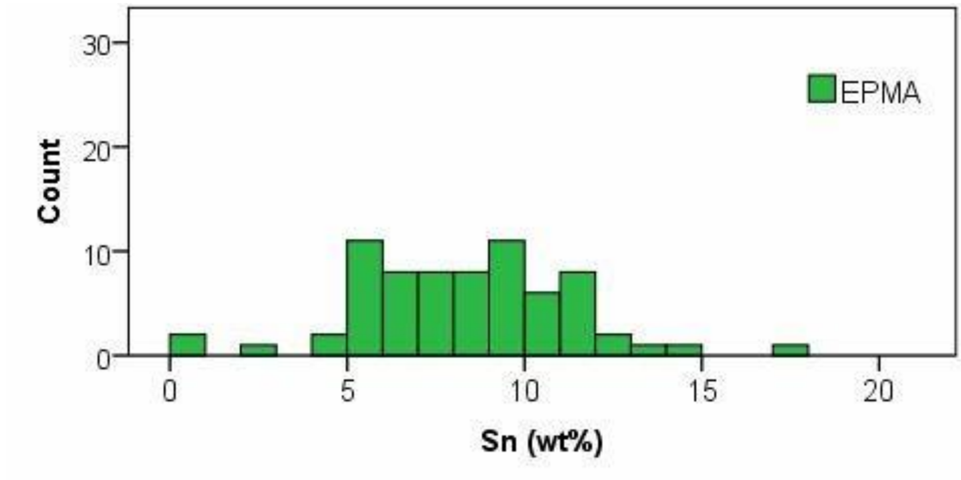


Figure 4.2. Scatterplot of tin against lead for all objects analysed (n=282) according to analytical method (EPMA, XRF)



a)



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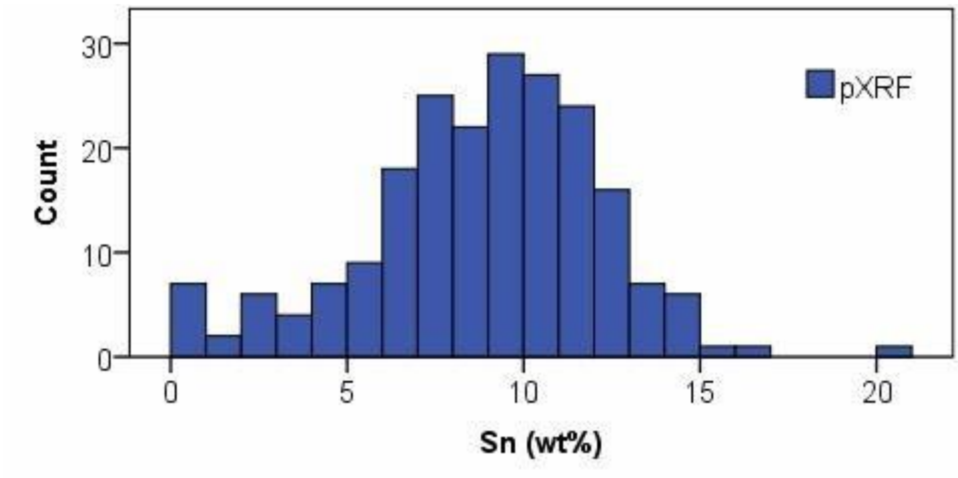
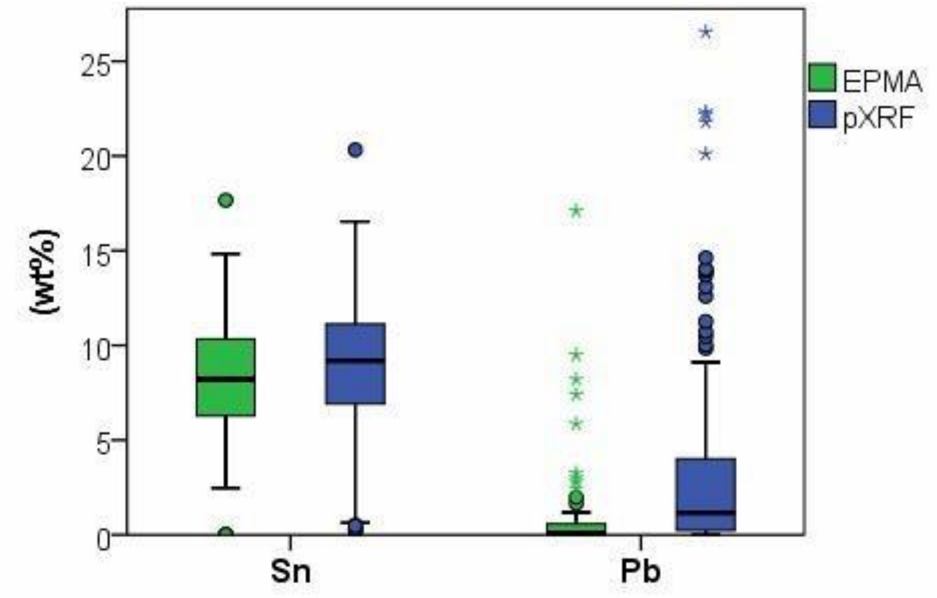
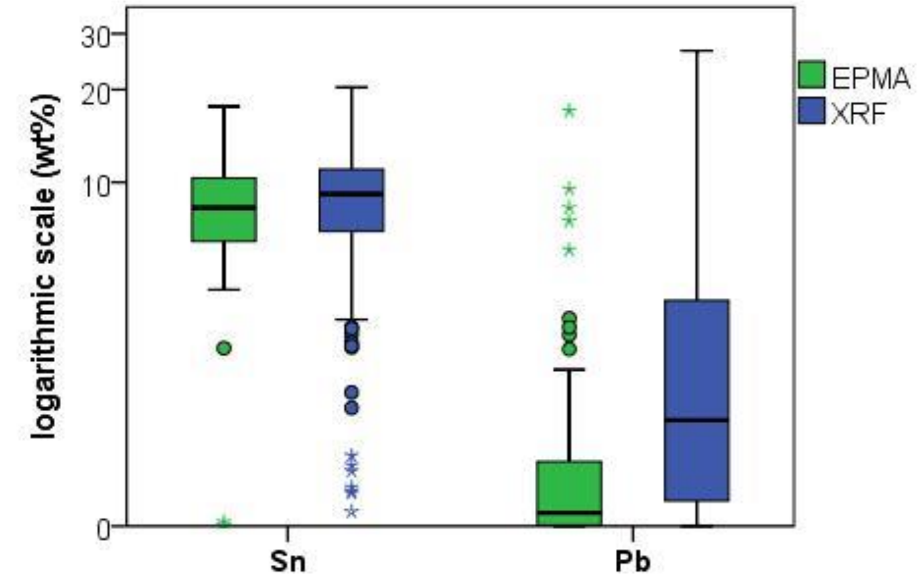


c)

Figure 4.3. Tin content distribution histograms for a) both analytical techniques (n=282), B) EPMA (n=70) and C) pXRF results (n=212) where a similar trend is visible, as well as the bimodal distribution in the EPMA dataset



a)



b)

Figure 4.4. Boxplots for tin and lead values for both EPMA (n=70) and pXRF (n=212) results in A) linear and B) logarithmic scale; greater comparability of results for tin is visible, whereas higher median and maximum values are noted for the lead content

Table 4.2. Summary table for copper, tin and lead concentrations in the sample (n=282)

	Cu (%)	**Sn (%)**	**Pb (%)**
mean	87.1	8.7	2.6
median	87.8	9.0	0.8
mode	88.0	9.0	<1.0
minimum	64.9	0.0	0.0
maximum	99.4	20.3	26.5
st.dev.	5.5	3.3	4.2

Table 4.3. Summary table of Cu, Sn and Pb according to the tin levels in the entire sample (pXRF & EPMA)

	<5% Sn (n=31)			5-10% Sn (n=149)			>10% Sn (n=102)		
	Cu	**Sn**	**Pb**	**Cu**	**Sn**	**Pb**	**Cu**	**Sn**	**Pb**
mean	92.7	2.5	2.5	88.0	7.8	2.7	84.0	12.0	2.4
median	93.5	2.8	0.4	88.9	7.9	0.7	85.3	11.5	0.8
min	71.2	0.0	0.0	64.9	5.0	0.0	65.0	10.0	0.0
max	99.4	5.0	21.8	94.0	10.0	26.5	89.3	20.3	22.3

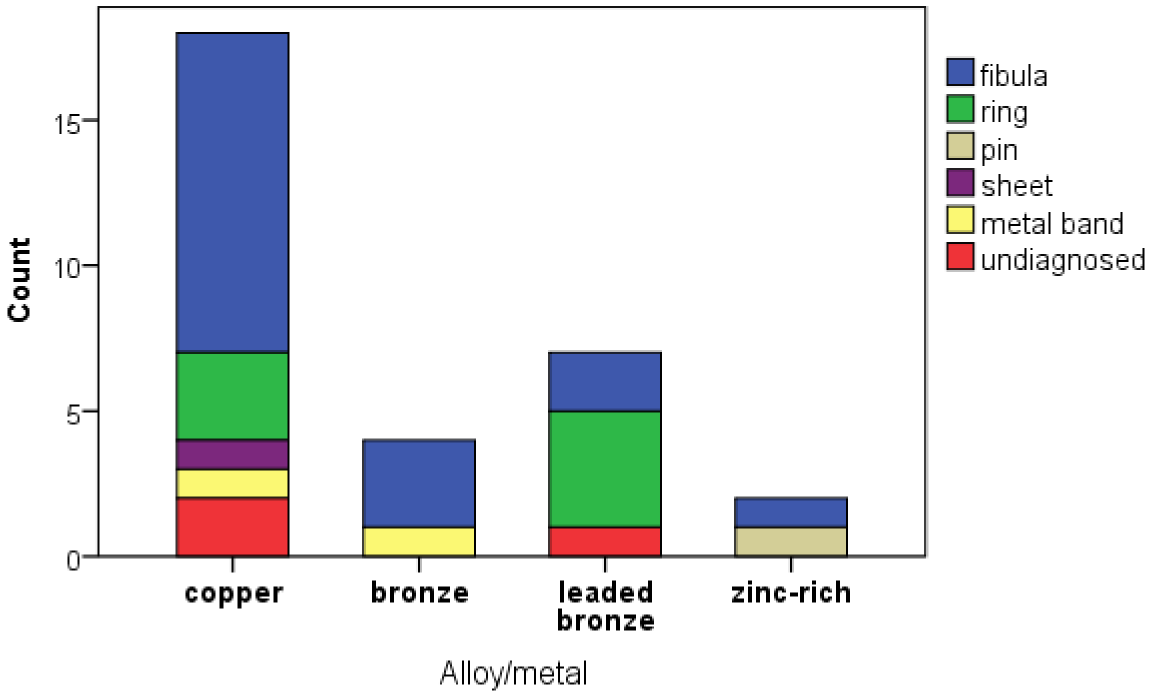


Figure 4.5. Barchart showing the distribution of alloys according to artefact type in the low tin group (<5% Sn) (n=31); it is worth noting that fibulae are represented in all alloy/metal groups

4.1.1 The tin content

Both pXRF and EPMA analyses (282 objects) showed a quite similar pattern for the tin content. This major alloying agent was found with mean (average), median (middle value in the dataset) and mode (value which appears most often in the dataset) values of 9% Sn suggesting a single-peak, normal distribution (Figure 4.3a, Table 4.2). In 88% of the sample tin was found between 5% and 15%, whereas only four objects contained between 16 and 20% tin and 31 objects below 5% tin (Figure 4.3, Table 4.3). Nonetheless, certain particularities were found across the two datasets. For example, tin as measured with the pXRF showed a distribution much closer to the normal curve with a single mode at 9% Sn, whereas EPMA results were rather evenly scattered within the 5-11% range and also showed a bimodal distribution with 11 objects with 5% and 9% tin (Figure 4.3b, c). However, both datasets pointed overall to a preferred copper-tin recipe with a mean of 8.5% tin (Table 4.1).

This low-tin group (1-5% Sn, 8% of the sample) mostly consists of binary tin bronze which is represented with 14 objects, whereas seven consist of leaded bronze and only pin BE 45749 is zinc-rich with a small tin content (Figure 4.5, Table 4.4) (see also below Chapter 4.2.4). Ancient copper alloys with small tin additions up to 3% Sn could have been the result of copper recycling operations and mixing with scrap bronze, while it would be difficult to argue for the deliberate addition of such small tin amounts (Patterson 1971, pp. 291, 308–309, Scott 2002, p. 89). Additionally, traces of tin, e.g. <1% Sn, could have occurred naturally as copper minerals with tin traces are often encountered on the earth's crust.

Tin-rich objects (>15% Sn, four objects) in their majority consist of binary tin bronze and only bead AE 451, which is the object with the highest tin content in the whole sample, was a tertiary alloy with 5% lead (Table 4.5). In addition, no correlation was noted between low or high tin concentrations and the artefact type or use (Figure 4.5). Finally, fibulae and rings which were most often found in the low tin group with 13 and 6 occurrences respectively do not reflect a preference of a particular alloy recipe as they also dominate the entire sample with 119 and 56 samples respectively too (Table 3.1).

Table 4.4. Compositions of the low tin (1-5% Sn) group (n=22; n.a., not analysed; n.d., not detected)

Inv.No.			Cu	Sn	Pb	Zn	Fe	Ni	Ag	Sb	As
M 1735.2	fibula	pXRF	94.8	2.5	0.00	0.30	0.64	0.17	*n.a.*	0.16	0.42
AE 776.1	ring	pXRF	94.8	2.6	0.00	0.30	0.85	0.17	*n.a.*	0.24	0.58
1310	ring	EPMA	95.3	2.8	8.21	0.00	0.02	0.03	0.01	0.52	0.07
AE 871	fibula	pXRF	92.4	3.0	1.39	0.32	1.91	0.20	*n.a.*	0.17	0.19
M 775	fibula	pXRF	93.5	3.0	0.01	0.23	2.01	0.16	*n.a.*	0.07	0.21
M 776.3	fibula	pXRF	93.0	3.2	0.00	0.32	1.71	0.24	*n.a.*	0.09	0.23
M 2125	fibula	pXRF	89.4	3.2	0.00	0.55	0.39	0.19	*n.a.*	0.23	0.53
M 2105	fibula	pXRF	92.2	3.5	2.80	0.35	0.86	0.15	*n.a.*	0.17	0.28
AE 936	ring	pXRF	94.7	3.7	0.59	0.32	0.24	0.14	*n.a.*	1.00	1.23
M 776.1	fibula	pXRF	89.3	4.2	0.15	0.36	2.49	0.27	*n.a.*	0.17	0.36
BE 45749	pin	pXRF	88.9	4.4	0.00	6.41	0.40	0.20	*n.a.*	0.16	0.18
AE 585	fibula	pXRF	89.5	4.5	0.77	0.28	1.59	0.29	*n.a.*	0.18	1.17
M 2117.2	fibula	pXRF	94.7	4.5	0.00	0.41	0.68	0.18	*n.a.*	0.11	0.25
AE 34	ring	EPMA	80.3	4.5	5.86	0.00	0.01	0.40	0.01	0.00	0.03
M 2262	fibula	pXRF	86.1	4.6	5.05	0.37	0.93	0.15	*n.a.*	0.08	0.19
M 1661.5	fibula	pXRF	71.2	4.7	4.70	0.29	0.41	0.16	*n.a.*	0.21	0.34
M 495.2	sheet	EPMA	93.5	4.7	0.43	0.00	0.23	0.04	*n.d.*	0.01	0.06
AE 95	ring	pXRF	90.9	5.0	13.70	0.64	0.32	0.23	*n.a.*	0.10	0.21
AE 773	ring	pXRF	94.8	2.5	8.50	0.19	0.20	0.15	*n.a.*	0.09	0.20
M 2292	pendant	pXRF	94.8	2.6	21.78	0.62	1.20	0.22	*n.a.*	0.13	0.17
M 2265	fibula	pXRF	95.3	2.8	0.75	0.33	0.10	0.22	*n.a.*	0.15	0.28
M 1345.2	fibula	pXRF	92.4	3.0	2.48	0.23	0.45	0.17	*n.a.*	0.21	0.56

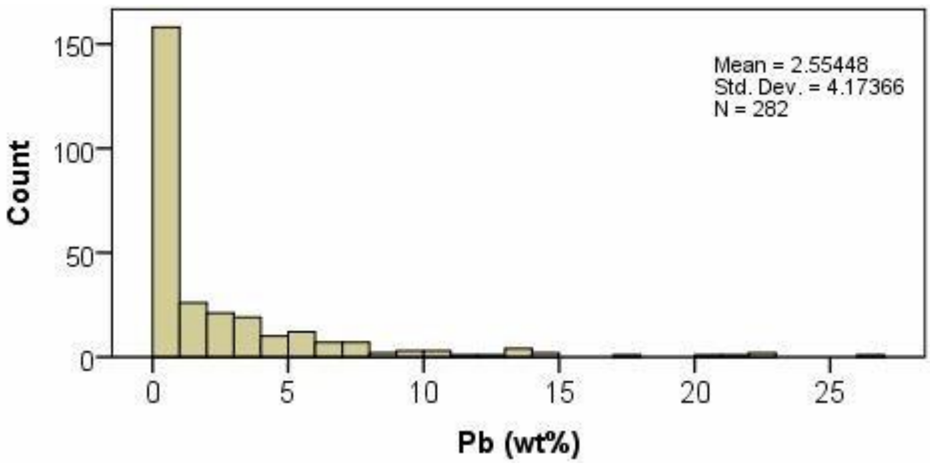
Table 4.5. Compositions of high tin objects (>15%) in the sample (n=4; n.a., not analysed; n.d., not detected)

Inv.No.		Cu	Sn	Pb	Zn	Fe	Ni	Ag	Sb	As
M44.18.7.13 vessel handle	pXRF	82.9	15.9	0.00	0.28	0.62	0.13	*n.a.*	0.08	0.12
AE 502 object	pXRF	81.3	16.5	0.00	0.29	0.99	0.21	*n.a.*	0.09	0.56
AE 899 syringe	EPMA	80.	17.7	0.57	*n.d.*	0.83	0.06	*n.d.*	0.15	0.17
AE 451 bead	pXRF	72.9	20.3	4.67	0.30	0.69	0.26	*n.a*	0.19	0.65

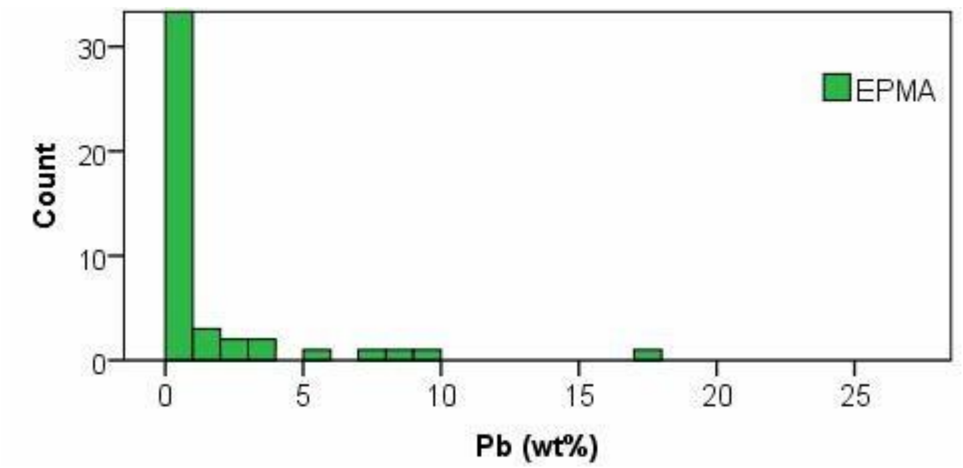
4.1.2 The lead content

Lead in the sample is largely present at impurity levels, namely below 4% lead. More than half of the objects (56% of the sample, 158 objects) as analysed with both analytical techniques do not contain more than 1% Pb (Figure 4.6a). This percentage is significantly higher in the EPMA dataset in which more than four in five samples contain <1% lead, whereas only one in two samples analysed with the pXRF fall into the same range (83% and 47% of the sample respectively) (Figure 4.7). Meanwhile, this discrepancy between the two datasets needs to be attributed to methodological concerns such as that object surface would have been richer in lead due to corrosion processes.

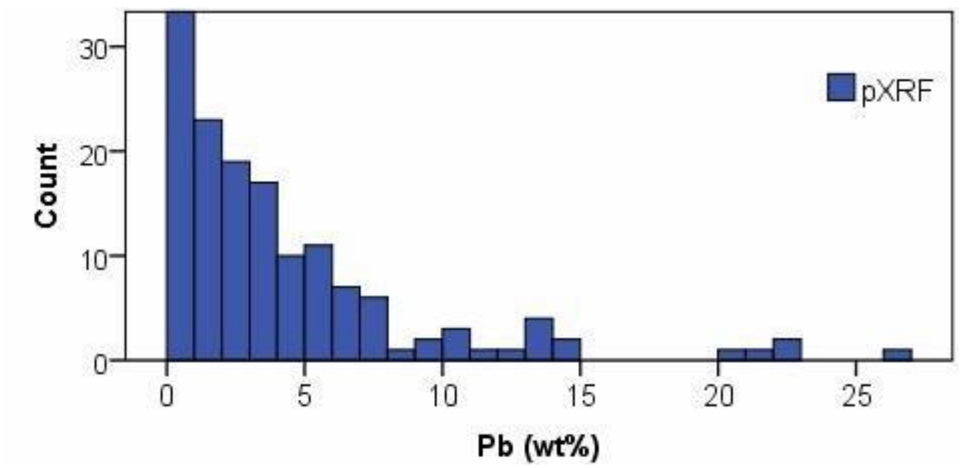
The presence of lead traces in the Pheraean bronzes fits well into the ancient copper technological tradition in which small amounts of lead are typically present in copper-based artefacts as impurities from the ores used. Due to this often co-occurrence of the two minerals, lead concentrations of up to 4% Pb may be considered accidental (Tylecote *et al.* 1977, Pernicka *et al.* 1990). Consequently, the vast majority of the sample (79%) as analysed with both techniques was found to contain lead at impurity levels, i.e. <4% Pb, and only one in five objects (58 objects, 21% of the entire sample) can be characterised as intentionally leaded. Meanwhile, EPMA and pXRF analyses showed a similar pattern of lead impurities in the majority of the samples (93% and 75% of EPMA and pXRF datasets respectively).



a)



b)



c)

Figure 4.6. Histogram showing the distribution of lead in the sample as analysed with A) both techniques (n=282), B) EPMA (n=70) and C) pXRF (n=212)

Furthermore, both datasets showed a marked decrease in the number of objects with more than 4% lead, while a more gradient slope is seen in the distribution curve for the pXRF (Figure 4.6b & c). Following the decrease in sample occurrences at 1% lead, the next steepest decline was found at 4% lead with a 3% decrease of the sample population (Figure 4.7). This shift in the lead distribution pattern could signify a difference in the mode of its addition, i.e. accidental versus deliberate, which further justifies the consideration of intentionally leaded alloys at >4% lead. In addition, in the pXRF analyses a more gradual decline in the number of occurrences is visible as element concentrations go up to 4-5% Pb (Figure 4.6b), whereas, the EPMA dataset shows a steeper decline at 1% lead (Figure 4.6c). Overall, a similar pattern for the lead content emerged in both datasets which suggests its presence as an impurity in the vast majority of the sample and its deliberate addition in a rather limited number of objects.

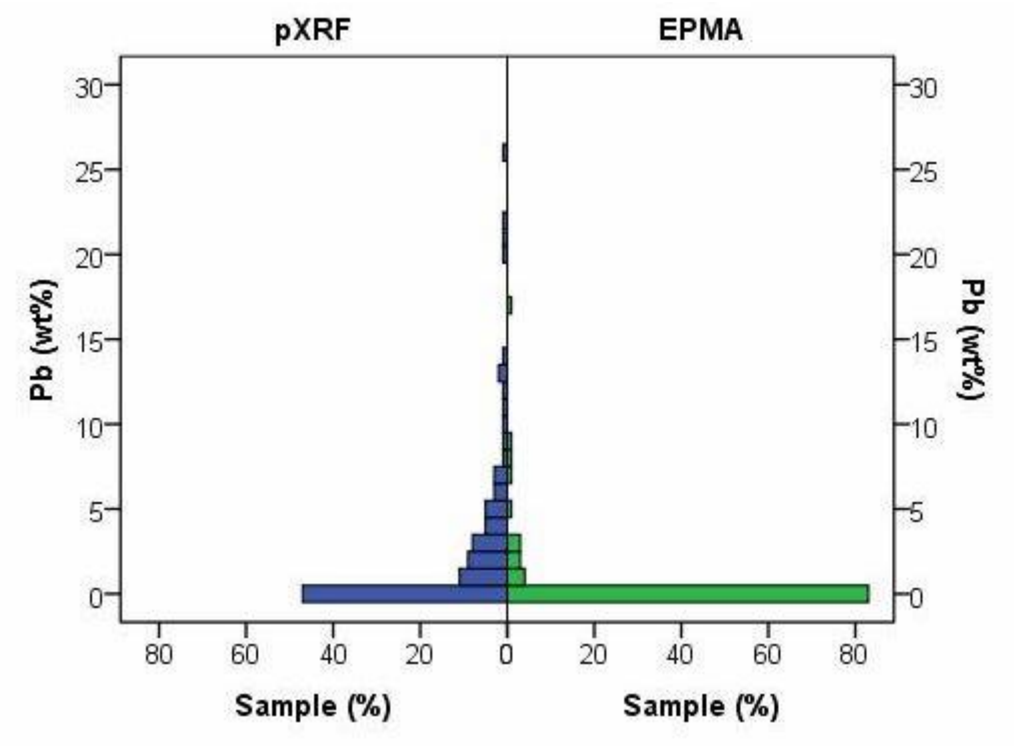


Figure 4.7. Lead content distribution in the EPMA and pXRF datasets (%)

Finally, slightly higher average values for both tin and lead produced during pXRF analysis can be satisfactorily justified on the basis of the nature of the analytical techniques and the properties of the elements themselves as already discussed such as surface enrichment phenomena (see 3.2.4). Thus, more consistent clustering of EPMA values for tin and particularly for lead, as reflected in the lower standard deviation values when compared to the pXRF ones, was expected (Table 4.1). Nevertheless, this did not significantly affect the overall results since both EPMA and pXRF data seem to consistently reproduce a pattern with average values of approximately 9% and 2.5% for the tin and lead respectively.

Table 4.6. Summary of occurrences for copper, bronze and leaded bronze in the analysed assemblage (N, number of cases) and percentages (%) of samples according to analytical method

	copper (Sn <4%, Pb <4%)		**bronze** (Sn >4%, Pb <4%)		**leaded bronze** (Sn >4%, Pb >4%)		**total (n=280*)**	
	N	(%)	N	(%)	N	(%)	N	(%)
EPMA	2	3	63	90	5	7	70	100
XRF	16	8	141	67	53	25	210	99
total	**18**	**6**	**204**	**72**	**58**	**21**	**280***	**99**

**Two objects have not been included in this table, namely the brass fibula M 1843.1 with 9% Zn and the zinc-rich pin AE 86/BE 45749 with 3% Sn and 6% Zn (see Table 4.12 below)*

4.2 Alloys and alloy recipes

Copper alloys dominate in the Pheraean assemblage, as pure copper was scarcely used on its own. Copper alloys occurred mainly after mixing with tin to produce bronze or with both tin and lead for leaded bronze. Below, discussion focuses on the characteristics of the different alloys present in the sample including binary (Cu-Sn) and ternary leaded (Cu-Sn-Pb) bronze which dominate in the sample, as well as fewer objects of unalloyed copper and zinc-rich copper alloys (Figure 4.8).

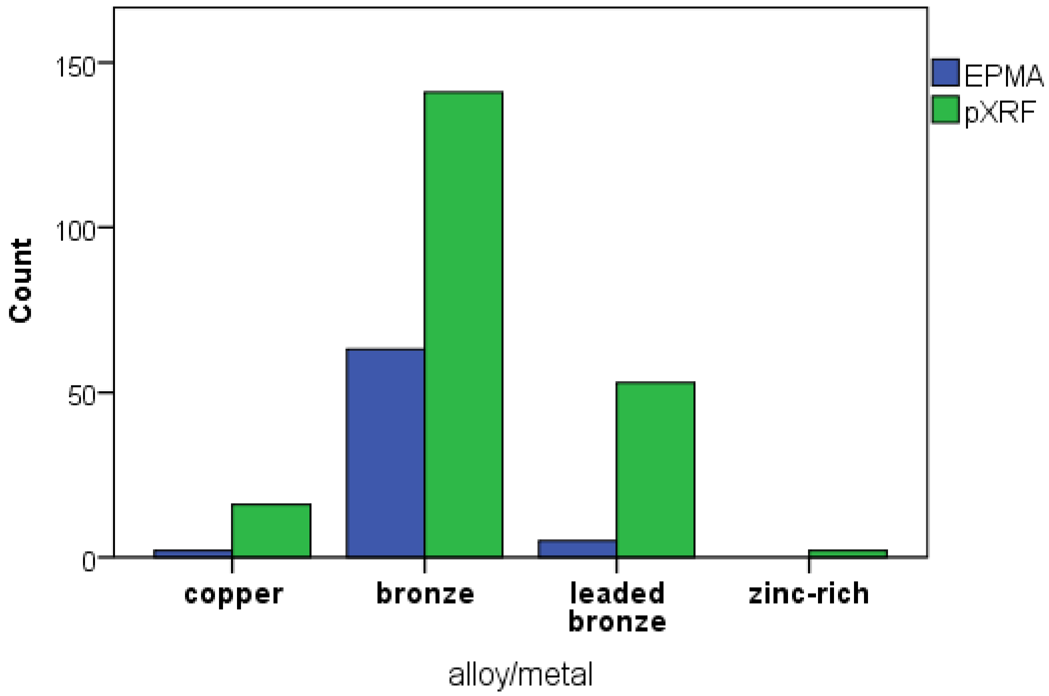


Figure 4.8. Barchart showing the frequency of the different alloys in the sample (n=282) as measured by both analytical methods (pXRF and EPMA, n=282)

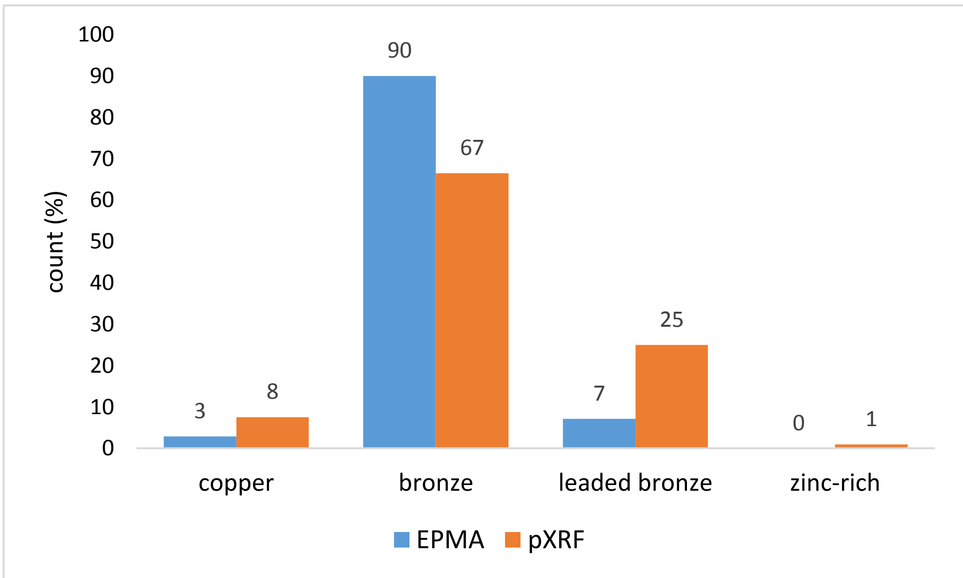


Figure 4.9. Barchart showing percentage frequencies (percent) of the different alloys according to analytical technique (EPMA, pXRF)

In addition, the predominance of bronze and leaded bronze objects in the EPMA and pXRF datasets respectively is better understood when looking at the artefact types most common in the two samples

(Figure 4.9). Thus, artefacts selected for invasive analyses mostly included small and thin artefacts which were more likely to comprise of lead-free alloys which would allow hammering and hot-working without unnecessary metal cracking (Staniaszek and Northover 1983, p. 265). On the contrary, larger and more bulky, often cast artefacts which would have undergone less mechanical stress during shaping were more often chosen for surface, non-invasive examination (Figure 3.12). Lead in antiquity is often present in alloys intended for casting and it is used to enhance alloy fluidity and castability, whereas its addition to copper would reduce the metal's hardness and mechanical properties, making it less suitable for hammering and for thin objects in general (Ingo, De Caro, Riccucci, Angelini, *et al.* 2006, pp. 515–516).

4.2.1 Unalloyed copper

Unalloyed copper is overall under-represented in the Pheraean assemblage. Characteristic feature of this group is that copper metal has not been mixed further in order to enhance its properties, but it was rather left by the metalworker in its state following the smelting and/or refining processes. All the same, unalloyed copper contained several additional elements as impurities (see Chapter 5).

Table 4.7. Unalloyed copper objects (<4% Sn) in the sample (n=18) as analysed by both techniques (n.a., not analysed)

Inv.No.	Description		Cu	Sn	Pb	Zn	Fe	Ni	Ag	Sb	As
1308	sheet	EPMA	99.4	0.0	0.38	0.00	0.00	0.02	0.04	0.01	0.07
AE 289	sheet	EPMA	99.2	0.0	0.24	0.00	0.00	0.02	0.11	0.07	0.07
M 1843.2	fibula	pXRF	98.9	0.1	0.00	0.35	0.15	0.23	*n.a.*	0.08	0.23
M 776.2	fibula	pXRF	98.7	0.3	0.00	0.36	0.16	0.16	*n.a.*	0.10	0.25
AE 487	object	pXRF	98.4	0.3	0.00	0.31	0.34	0.23	*n.a.*	0.10	0.30
AE 900	ring	pXRF	97.4	0.5	0.00	0.29	1.32	0.12	*n.a.*	0.08	0.24
AE 116	object	pXRF	97.0	0.6	0.00	0.32	0.74	0.17	*n.a.*	0.09	1.06
M 1345.3	fibula	pXRF	96.9	0.3	0.06	1.09	0.80	0.56	*n.a.*	0.12	0.22
AE 776.1	ring	pXRF	96.3	1.5	0.00	0.30	0.85	0.17	*n.a.*	0.24	0.58
M 2125	fibula	pXRF	95.3	2.8	0.00	0.55	0.39	0.19	*n.a.*	0.23	0.53
M 776.3	fibula	pXRF	94.8	2.6	0.00	0.32	1.71	0.24	*n.a.*	0.09	0.23
M 775	fibula	pXRF	94.8	2.5	0.01	0.23	2.01	0.16	*n.a.*	0.07	0.21
M 2117.2	fibula	pXRF	94.7	3.7	0.00	0.41	0.68	0.18	*n.a.*	0.11	0.25
AE 936	ring	pXRF	93.5	3.0	0.59	0.32	0.24	0.14	*n.a.*	1.00	1.23
AE 871	fibula	pXRF	93.3	2.5	1.39	0.32	1.91	0.20	*n.a.*	0.17	0.19
M 776.1	fibula	pXRF	93.0	3.2	0.15	0.36	2.49	0.27	*n.a.*	0.17	0.36
M 2105	fibula	pXRF	92.4	3.0	2.80	0.35	0.86	0.15	*n.a.*	0.17	0.28
AE 585	fibula	pXRF	92.2	3.5	0.77	0.28	1.59	0.29	*n.a.*	0.18	1.17
		mean	**95.9**	**1.7**	**0.36**	**0.34**	**0.90**	**0.19**	**0.08**	**0.17**	**0.41**

The unalloyed copper group consists of 18 objects in the entire sample. Tin and lead with mean concentrations of 1.7% and 0.4% respectively are at accidentally occurring impurity levels (Table 4.7). Concentrations of 1% arsenic and 1.3% iron detected in the object AE 116 and ring AE 900 respectively are also taken as accidental. The metal sheets 1308 and AE 289 are amongst the purest of the unalloyed copper group, with a copper content >99% and minimal trace elements. However, their compositions should not to be taken as exceptional amongst the unalloyed copper group since they have been produced with the EPMA which is generally more accurate at such low element concentrations and on clean metal, away from any surface contamination which may have been at reflected the pXRF results. Overall, systematic differences for the trace elements in the unalloyed group (Sn, Pb, Zn, Fe, Ni, and As) across the two datasets are primarily attributed to the analytical instruments' properties and not as characteristic of the overall object composition.

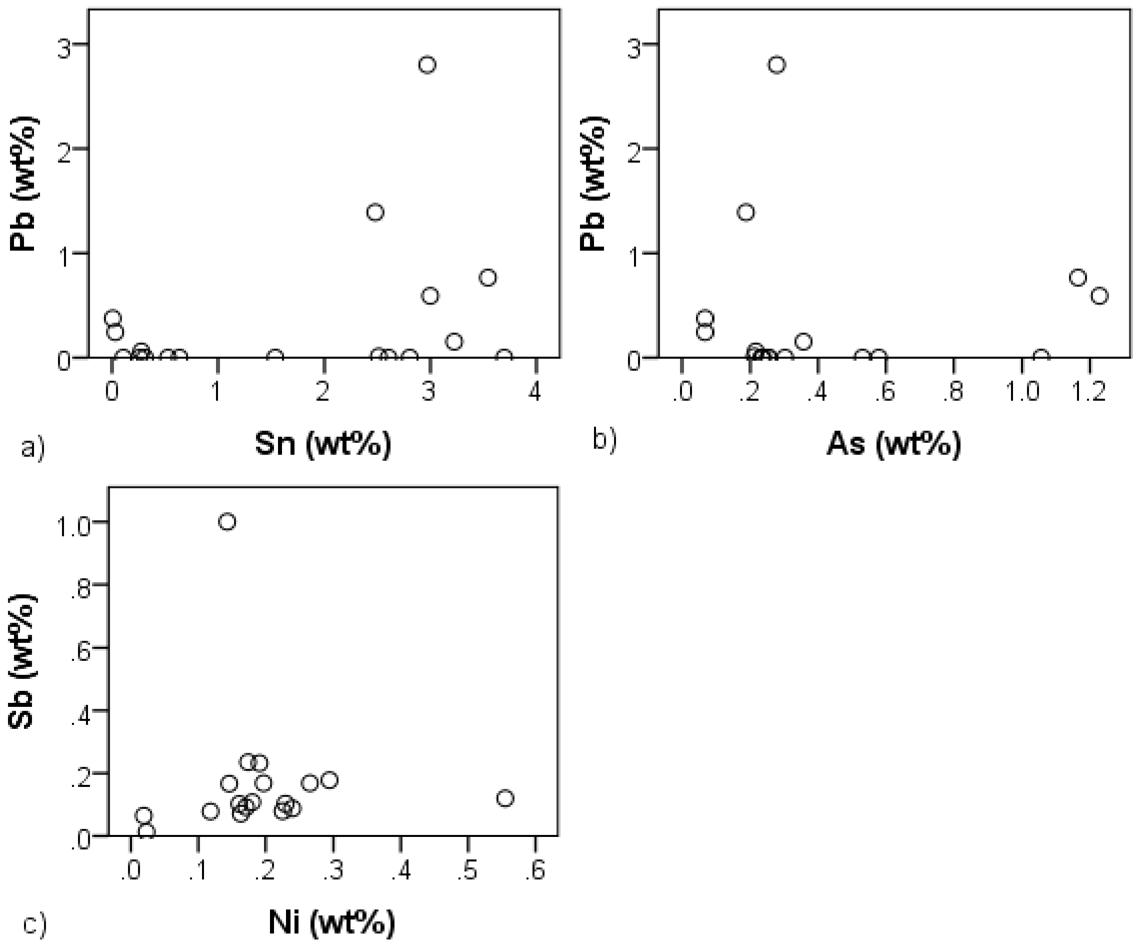


Figure 4.10. Scatterplots of A) tin against lead, B) arsenic against lead and C) nickel against antimony for the <1% Sn copper group (n=9, EPMA & pXRF); the outlier in scatterplot A is zinc-rich fibula M 1843.1

For the lead and tin contents no specific correlation was noted. Nonetheless, two groups could be possibly identified, namely one with tin below 1% and lead below 0.5%, and a second one with approximately 3-4% tin and variable lead values up to 3% Pb (Figure 4.10a). Similarly, objects with low arsenic values present variable lead concentrations, whereas typically higher arsenic content is seen in objects with lower lead with the exception of a couple of objects with 1.2% As and 1% Pb (ring AE 936 and fibula AE 585) (Figure 4.10b). Finally, a slightly positive correlation trend is found between the nickel and antimony values again with the exception of two outliers, namely fibula M 1345.3 and ring AE 936 (Figure 4.10c). However and despite the above remarks, the population of this group in the sample is not sufficiently large in order to allow for any definite conclusion on the trace element patterns and correlations to be drawn.

4.2.2 Tin bronze

Binary copper-tin alloys comprise the largest compositional group with 204 occurrences in the entire sample (Figure 4.8). The main characteristic of this group is that tin is to be found in levels above 4% Sn suggesting its deliberate addition, while lead is only present as an impurity (<4% Pb) with a mean value just below 1% and a median of 0.5% Pb (Table 4.9). The level of tin which is to distinguish between unalloyed copper and tin bronze has been dictated by analyses of the assemblage itself since there is a marked increase in the objects containing >4% tin (Figure 4.2). Furthermore, this pattern is even more pronounced in the EPMA dataset where objects with tin between <0.05% and 4% Sn are absent with the single exception of ring 1310 which contains 2.5% tin but also 8% lead (Figure 4.1a). Tin contents below 4% could be taken as traces of recycling strategies where fresh copper metal was mixed with scrap bronze (as also discussed above).

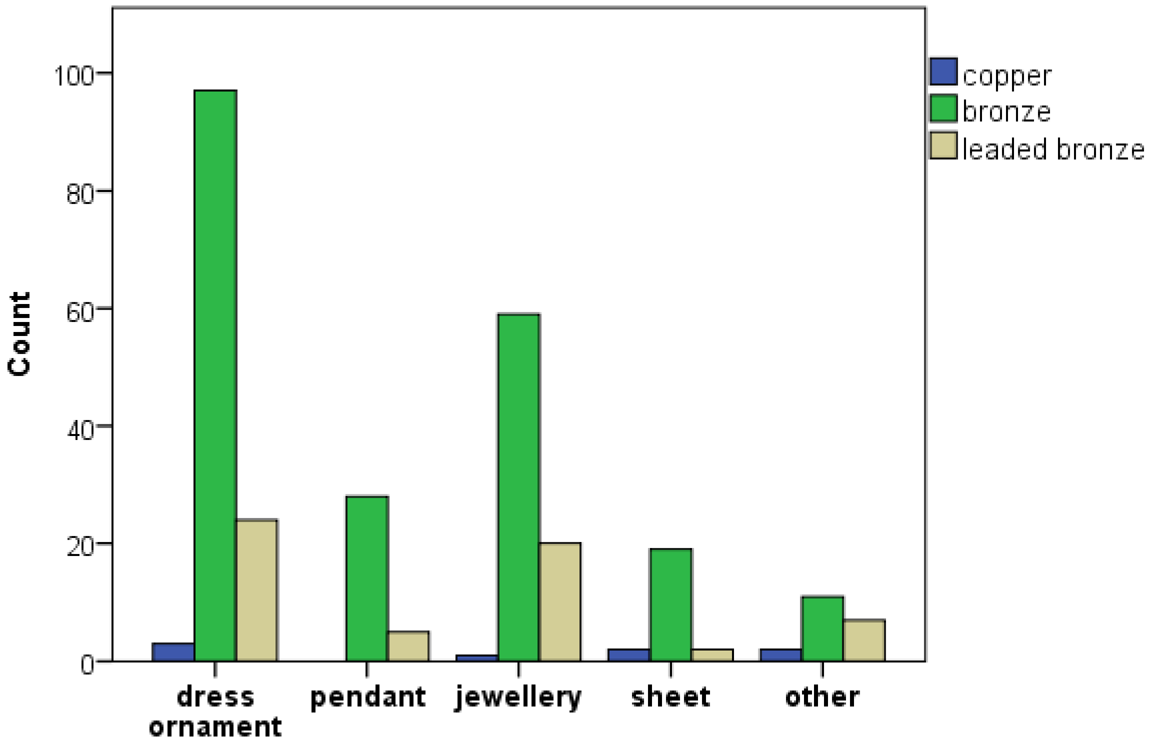


Figure 4.11. Barchart showing the distribution of the different artefact categories according to metal/alloy

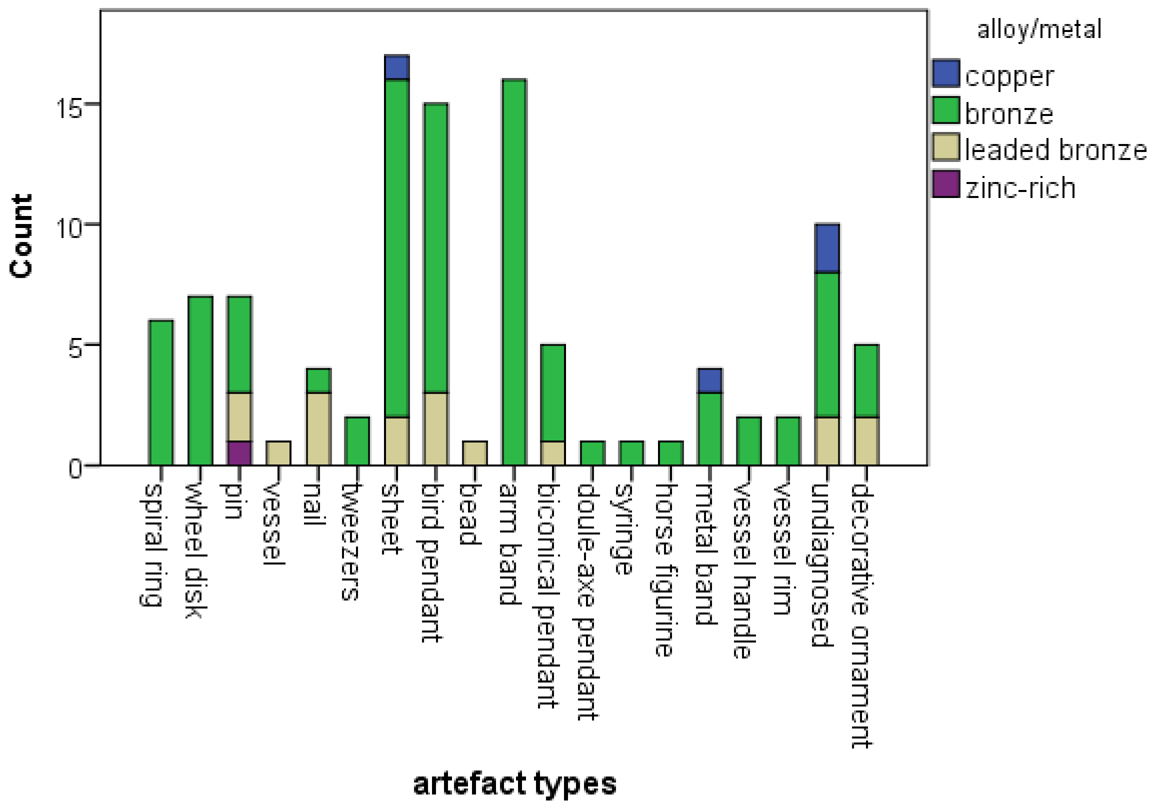


Figure 4.12. Barchart of artefact types according to alloy group (fibulae and rings not included due to their many occurrences in the sample, i.e. 119 and 56 respectively)

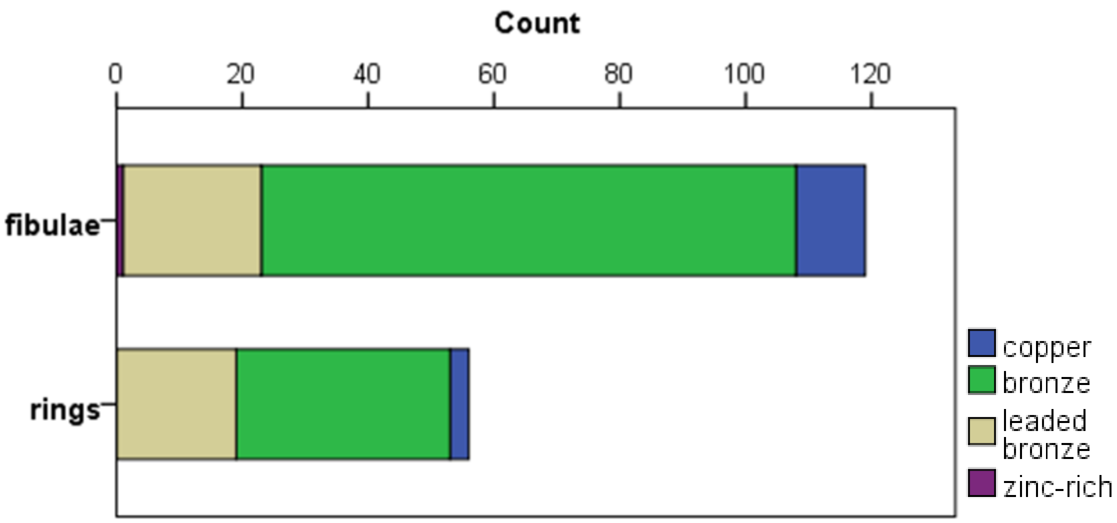


Figure 4.13. Fibulae and rings in the sample according to alloy/metal composition

The tin content of binary bronze spans between 4% and up to 17% Sn with an average of 9% Sn (Table 4.8), which was seen across the two datasets. Similar mean, median and mode values (9-10%) for the tin content point to a normal distribution pattern in which the majority of the objects (92% of the bronze group) contain between 5% and 15% with a single peak at 9% Sn (Figure 4.20). All artefact types are represented in the tin bronze group, and even though fibulae and rings are to be found most often with 85 and 34 occurrences respectively, this again is related to their prevalence in the entire sample too (Figure 4.11, Figure 4.13). Nonetheless, there are certain artefact types in the sample that solely consist of binary copper-tin alloys such as the spirals, the tweezers, certain pendant types including the wheel disks, and the arm bands (Figure 4.12).

Table 4.8. Tin and lead contents summary table for bronze and leaded bronze artefacts

	bronze			**leaded bronze**		
	mean (wt%)		total	mean (wt%)		total
	Sn	**Pb**	**N**	**Sn**	**Pb**	**N**
EPMA	8.7	0.4	63	7.1	9.6	5
pXRF	9.7	1.2	141	8.9	8.9	53

Table 4.9. Summary of averages for both EPMA and pXRF results according to alloy type

	Sn (%)			**Pb (%)**		
	bronze	**leaded bronze**	**all**	**bronze**	**leaded bronze**	**all**
mean	9.4	8.7	8.7	0.9	9.0	2.6
median	9.5	7.9	9.0	0.5	7.0	0.8
mode	9.8	6.6	9.8	0.0	5.1	0.0
st.dev.	2.6	3.2	3.3	1.1	5.3	4.2

4.2.2.1 High tin bronze

Very few binary bronze samples are particularly rich in tin as only three artefacts contained tin in excess of 15%, namely spiral AE 899 with 17.6%, a metal sheet with an attached ring with 16.5% and a vessel handle M 4418.7.13 with 15.9% tin (Figure 4.14, Figure 7.32). The aforementioned objects stand out not only due to their composition, but also their typologies as they are encountered with very few occurrences in the excavated assemblage too. During the macroscopic investigation of some 3000 objects no duplicates of the vessel handle or the sheet with attached ring were found.

a) 

c) 

Figure 4.14. High tin objects (>15% Sn) in the binary bronze group: A) vessel handle M 4418.7.13 and B) metal sheet with attached ring AE 502 (analysis on metal sheet only)

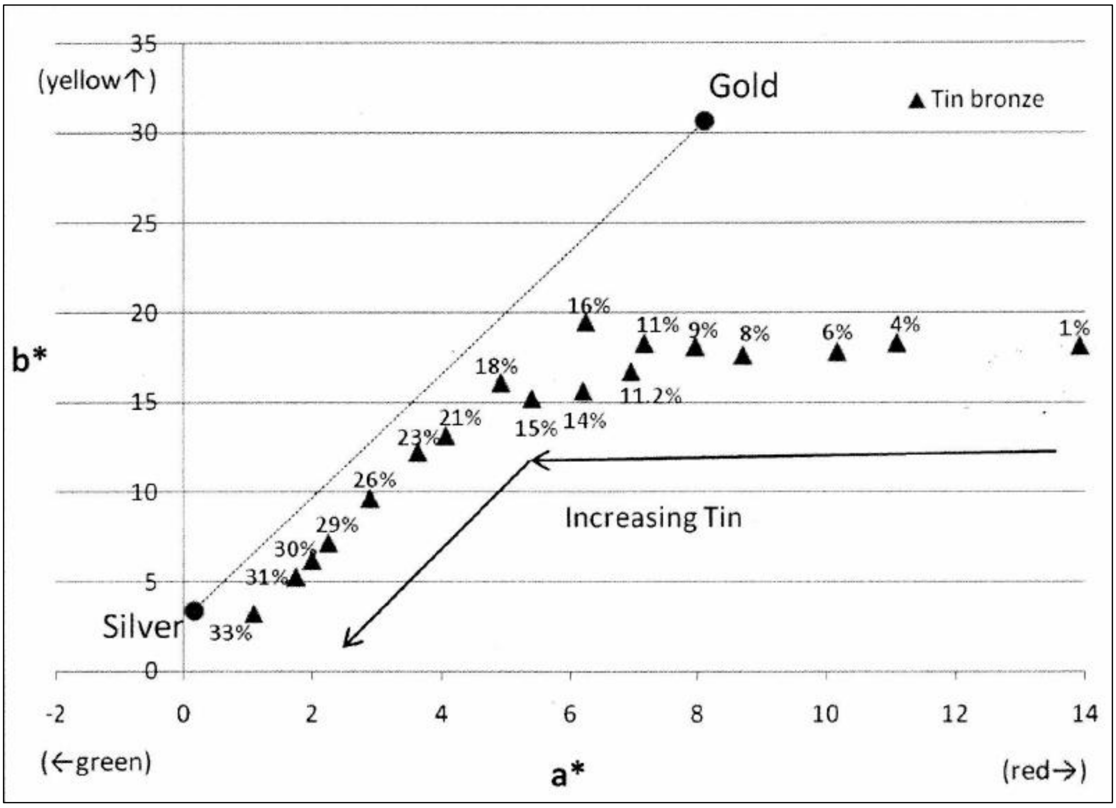


Figure 4.15. CIELAB colour space diagram for binary bronzes with various tin contents (after Fang and McDonnell 2011, p. 56, figure 1)

A binary copper alloy rich in tin would have been a quite hard and brittle alloy and it is not surprising that it is not often encountered. The vast majority of the offerings span around a bronze recipe of one part tin and nine parts copper which is the bronze recipe often encountered in ancient bronzes due to its optimum properties since it combines maximum hardness with minimum brittleness, and it has a golden- or silver-like tint to resemble precious metals and alloys (Fang and McDonnell 2011, p. 56, figure 1) (Figure 4.15, 4.16).

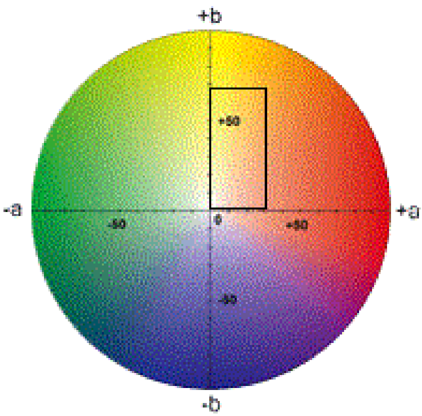


Figure 4.16. CIELAB colour space diagram; the black square corresponds to the area represented in chart of Figure 4.18

4.2.3 Leaded bronze

The leaded bronze group comprises of ternary copper-tin-lead alloys with tin and lead concentrations larger than 4% (see also Chapter 4.1 for a discussion between impurity levels and deliberate additions for these elements). As with the unalloyed copper and tin bronze groups, EPMA and pXRF results produced similar mean values and overall patterns for the major elements (Table 4.8). Overall, one in five objects (58 objects) from the entire sample consisted of leaded bronze. Leaded bronze objects have a lead content between 4% and 26.5% Pb, and tin between 2.5% and 20% Sn (Figure 4.18). Meanwhile, lead has not been added to pure copper, but was typically found to purposefully alloyed copper with tin concentrations between 4% and 15% tin. A couple of exceptions to the above pattern included the ring 1310 with 2.5% and bead AE 451 which contains 20% tin. This apparent preference for medium-tin leaded bronzes took advantage of the beneficial properties of both elements while avoiding the production of dysfunctional alloys. Additions of lead into pure/unalloyed copper would result in a metal difficult to shape and too soft to use, whereas a leaded bronze alloy rich in tin would be brittle enough to easily crack already during hammering and hot-working.

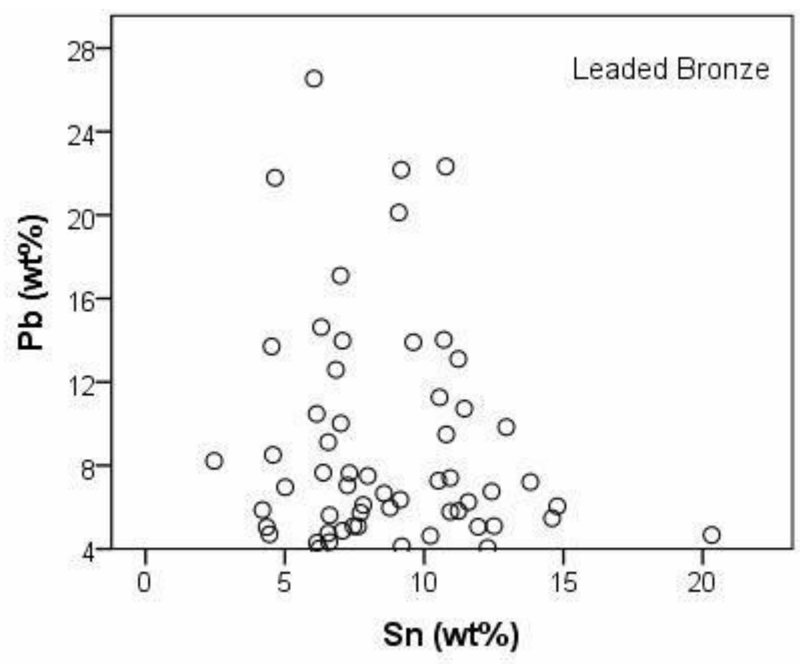


Figure 4.17. Scatterplot of tin against lead for leaded bronzes (EPMA and pXRF)

Leaded tin-rich bead AE 451 is an exceptional find in the entire sample not only compositionally, but also typologically. It is of quite small dimensions with a diameter of no more than 0.5 cm and it is a single find not only in the sample but in the whole of the Pheraean assemblage. Its small dimensions could also account for its particular composition as this high tin leaded bronze would be most probably unsuitable for a larger object due to its fragile nature. Even though the rarity of this artefact type could be the result of its small size that could make it pass unnoticed in the field, its particular composition along with its typology render it a unique find and further suggest its production via a rather distinct technological tradition from the mainstream one as seen for Early Iron Age mainland Greece.

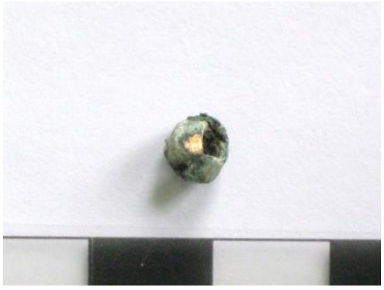


Figure 4.18. Bead AE 451 of high tin leaded bronze; single find in the assemblage

4.2.3.1 Tin distribution in leaded bronze

The tin content in the leaded bronze group, as opposed to the binary bronzes, shows a different distribution pattern even though it still has an average of approximately 9% Sn (Figure 4.19). The bronze group shows an almost textbook normal distribution with mean, median and mode values closely clustering (9.0-9.8) (Figure 4.20), whereas for leaded bronze all three averages showed a positively skewed distribution in which the mean is higher than the median (7.9%) and the latter higher than the mode (6.6%) (Table 4.9). In addition, tin values for leaded bronze showed two modes, i.e. two peaks, one at 6% and a second at 11% tin (Figure 4.21). This pattern is quite different from the single-peak tin distribution seen in the binary bronze and could point to two different alloying habits and two preferred bronze recipes for leaded bronze (for a more detailed discussion of this bimodal distribution see Chapter 6.1).

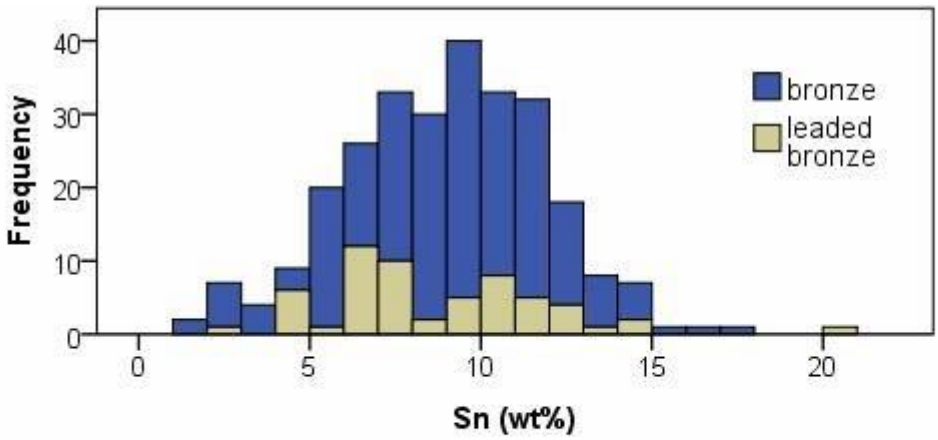


Figure 4.19. Barchart showing the tin content in the bronze and leaded bronze objects in the sample (EPMA and pXRF)

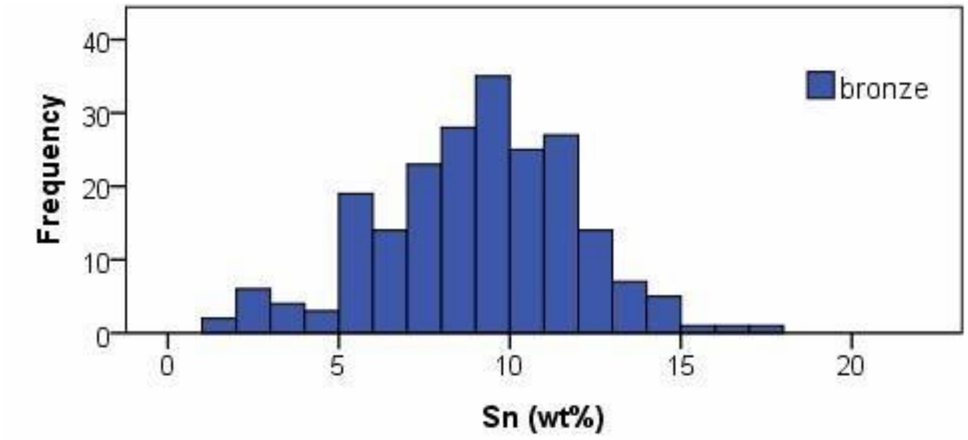


Figure 4.20. Histogram of tin distribution in the sample; pure copper objects (<1% Sn) are excluded (n=274)

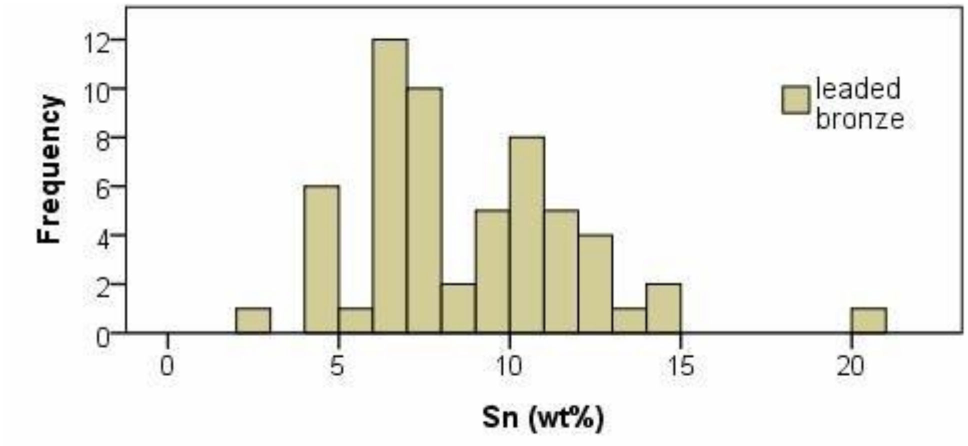


Figure 4.21. Histogram of the tin content in leaded bronzes

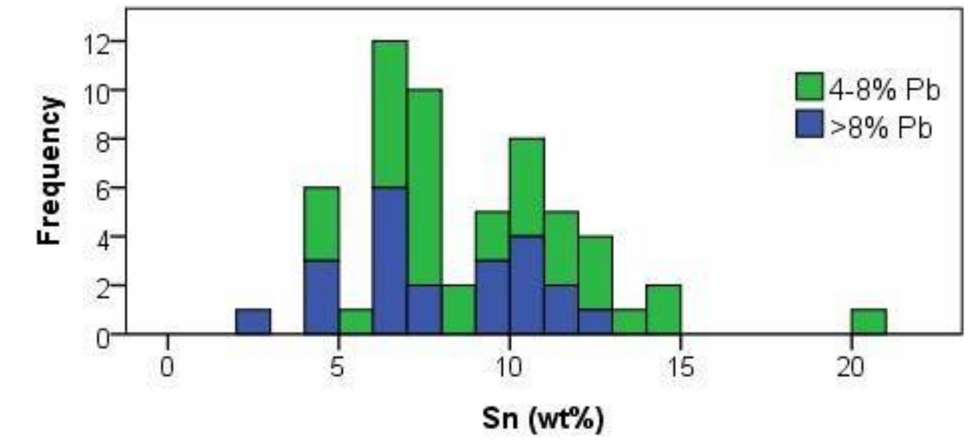


Figure 4.22. Histogram of tin content for the low and high leaded bronze alloys

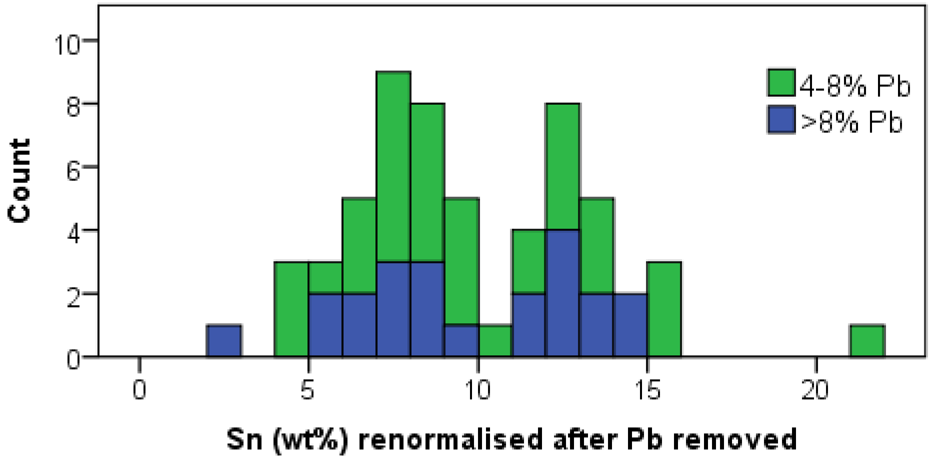


Figure 4.23. Histogram of the tin content distribution renormalised after the lead content was subtracted according to low and high leaded bronze objects

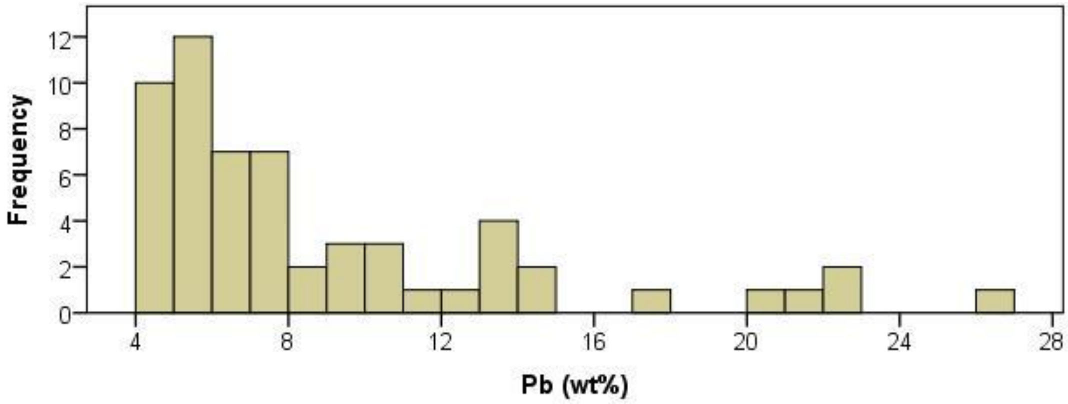


Figure 4.24. Lead distribution histogram for the leaded bronze group (n= 58, EPMA and pXRF)

4.2.3.2 Lead distribution in leaded bronze

Lead distribution showed a sharp decrease in the number of objects with more than 8% Pb which could possibly split the sample in two groups, namely one with 4%-8% and a second with >8% lead (Figure 4.17, Figure 4.24). The majority of the objects fall into the low lead group (36 samples) and seem to have a wider distribution for the tin content with a standard deviation of 3.6, while the group richer in lead (>8% Pb) which consists of 22 samples showed a narrower tin distribution (stand. dev. 2.8) (Table 4.10, Figure 4.25). Even though tin distribution in these lead groups shows a preference of slightly higher tin contents for the low lead group (Table 4.10), this is disproved if the tin content is renormalised after the lead content has been removed (Table 4.11, Figure 4.23). Thus, renormalised results for the tin content showed a very consistent pattern where variable amounts of lead are added to tin bronze with an average of 10% Sn with similar standard deviation values. Finally, a relatively better control over the addition of lead has been noted for the low lead group (4-8% Pb) with a standard deviation of 1.1%.

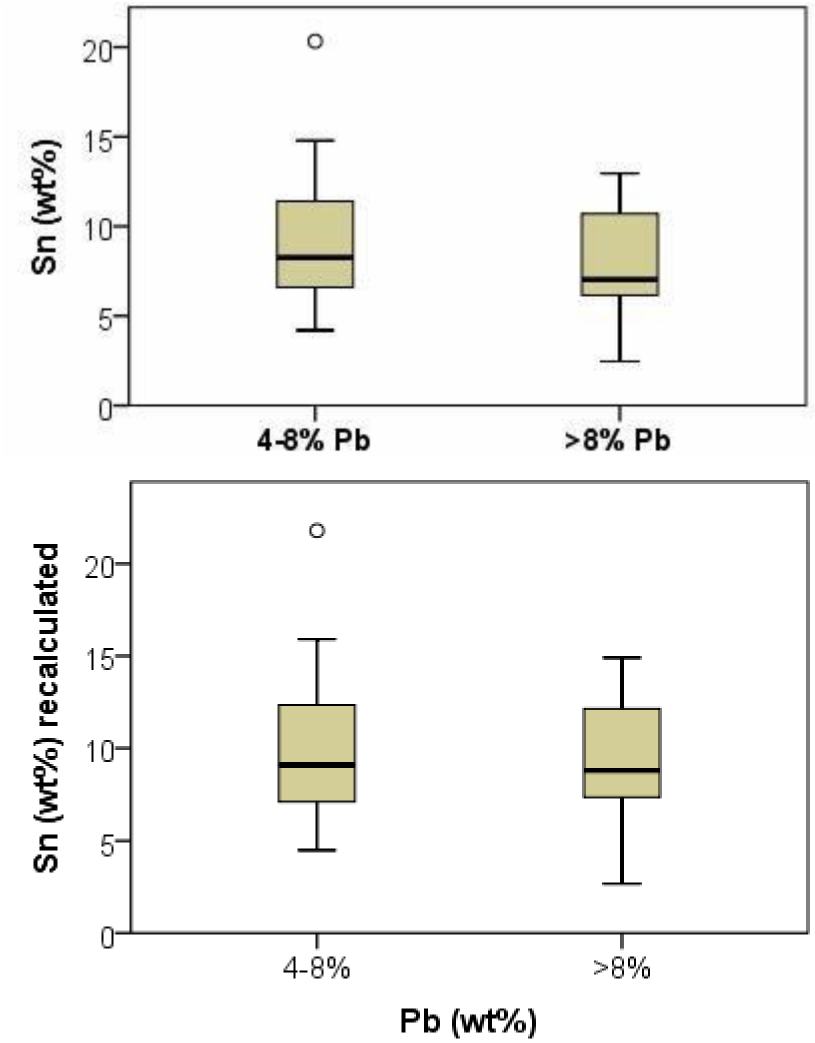


Figure 4.25. Boxplot of tin distribution (A) before and (B) after renormalisation in low (4-8%) and high (>8%) leaded bronze alloys

Table 4.10. Summary of lead and tin contents in leaded bronze alloys (EPMA and pXRF)

	leaded bronze 4-8% Pb (N=36)		leaded bronze >8% Pb (N=22)		all leaded bronze >4% Pb (N=58)	
	Pb	**Sn**	**Pb**	**Sn**	**Pb**	**Sn**
mean	5.7	9.2	14.3	8.0	9.0	8.7
median	5.8	8.3	13.4	7.1	7.0	7.9
mode	5.1	6.6	14.0	4.6	5.1	6.6
st.dev.	1.1	3.5	5.2	2.8	5.3	3.3
skewness	0.2	**1.0**	0.9	**-0.1**	1.6	0.8

Table 4.11. Summary table of tin (renormalised after Pb removed) and Pb for the low and high lead groups

	leaded bronze 4-8% Pb (N=36)		leaded bronze >8% Pb (N=22)		all leaded bronze >4% Pb (N=58)	
	Pb	**Sn**	**Pb**	**Sn**	**Pb**	**Sn**
mean	5.7	**9.9**	14.3	**9.6**	9.0	**9.8**
median	5.8	**9.1**	13.4	**8.8**	7.0	**9.0**
st.dev.	1.1	**3.7**	5.2	**3.4**	5.3	**3.6**

4.2.4 Zinc-rich objects

In the assemblage there is a group of zinc-rich objects with >1% Zn which have been detected only during pXRF analysis. This group is considered here as zinc-rich and the zinc content as accidentally present from the use of zinc-rich copper ores. Such natural brasses (copper-zinc alloys) have often been described in antiquity as oreichalkos.

4.2.4.1 Natural and deliberate brasses

Oreichalkos is a term often found in ancient Greek and Roman literature. Following the extended discussion on its literary origins it has been most arguably used to describe a naturally occurring copper alloy resulting from the smelting of zinc-bearing copper ores (Craddock 1978, p. 1, 1998, pp. 3–5). Even though objects of such composition are found in the archaeological record from the second half of the 2nd millennium onwards (Thornton *et al.* 2002, Craddock and Eckstein 2003, p. 216, Thornton and Ehlers 2003), it was not before the Roman times in the 1st century BC that the technology to produce brass (a binary copper-zinc alloy) was mastered through the cementation process, i.e. the permeation of solid state metallic copper by zinc vapour in lidded crucibles (Bayley 1998, p. 9, Rehren 1999, Craddock and Eckstein 2003, p. 217, Rehren and Martinón-Torres 2008, p. 168). This technological advance triggered the mass production of brasses, including its use in Roman coinage, but it also allowed the control and standardisation of zinc intake into copper with a maximum of 28-33% Zn (Craddock 1978, p. 1, Craddock and Eckstein 2003, p. 227). Finally, zinc metal was occasionally produced in antiquity as a by-product of silver smelting (Rehren 1996, Craddock 1998, pp. 4–5).

Zinc, due to its volatility, could not have been alloyed with copper following the traditional know-how of prehistoric antiquity, i.e. melting and mixing of metals (Rehren and Martinón-Torres 2008, p. 168). Heating zinc during smelting in temperatures well above its boiling temperature of 907^{o}C in ancient kilns would result in its loss through evaporation. Hence, despite that zinc is often found in copper ores as a sulphide (ZnS), much of it would have been evaporated already during roasting, i.e. the conversion of sulphides into oxides prior to smelting of copper ores (Craddock 1978, p. 2). Nonetheless, small and random amounts of zinc metal could have potentially ended up in the metal produced under exceptional circumstances strongly depending on the operating conditions within the metallurgical furnace. Smelting of oxide ores which involves reducing conditions, for instance, could have produced a copper alloy with substantial zinc contents (Craddock 1978, p. 2).

Examples of early pure zinc objects are few and point to the limited circulation of zinc objects in Greece and surrounding regions. Even though there has been some evidence supporting the presence of zinc objects from the Hellenistic period as, for example, indicated by a 3rd-2nd century BC zinc sheet from the Athenian agora (Farnsworth *et al.* 1949), zinc metal could not have been used for the production of zinc-containing alloys since the skill that would allow its systematic and controlled production was lacking. Consequently, zinc-containing copper-based objects dating prior to the Roman period are best described as accidental/natural brasses. Preference of oreichalkos over pure copper or (leaded) bronze by early smiths and their customers could have been a deliberate decision due to its visual properties, but no deliberate alloying of copper with zinc took place. Oreichalkos was considered an expensive and exotic alloy not only due to its golden-like colour as a 15% zinc brass would have a brighter yellow colour than pure gold itself (Fang and McDonnell 2011, p. 57), but due to its rarity too which potentially added further to its value.

Table 4.12. Objects in the sample with >1% Zn; such results were detected only during pXRF analyses (n=8)

Inv.No.	Description	Cu	Sn	Pb	Zn	Fe	Ni	Ag	Sb	As
M 1843.1	fibula	88.5	0.5	0.80	9.28	0.58	0.12	*n.a*	0.07	0.24
AE 86/BE 45749	pin	89.4	3.2	0.00	6.41	0.40	0.20	*n.a*	0.16	0.18
M 2122.2	fibula	83.6	7.1	4.87	2.63	0.96	0.26	*n.a*	0.41	0.19
AE 483	ring	87.5	8.3	0.00	1.41	2.27	0.23	*n.a*	0.19	0.20
AE 721	ring	80.5	12.3	4.05	1.18	1.34	0.27	*n.a*	0.25	0.17
AE 427	wheel disk	85.7	10.3	0.33	1.11	1.84	0.23	*n.a*	0.21	0.25
M 1345.3	fibula	96.9	0.3	0.06	1.09	0.80	0.56	*n.a*	0.12	0.22
M 2226	fibula	85.2	8.6	3.86	1.06	0.63	0.23	*n.a*	0.09	0.37

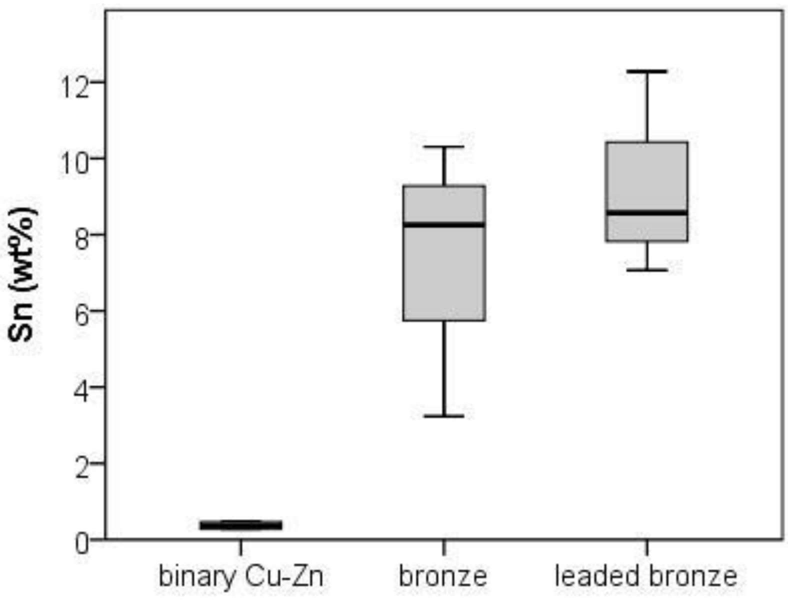


Figure 4.26. Five-point boxplot showing the tin distribution in the zinc-rich group according to alloy recipe: Cu-Zn (binary Cu-Zn, n=2), Cu-Sn-Zn (bronze, n=3) and Cu-Sn-Pb-Zn alloys (leaded bronze, n=3)

4.2.4.2 Zinc in the Pheraean sample

Taking into consideration the early dating of the Pheraean assemblage around the 8th-7th centuries BC and the compositional characteristics of the zinc-rich samples, namely with >1% zinc, they are best described as natural brasses. Zinc-rich objects in the sample have a variable zinc content ranging from 1% to 9% Zn with average and median values of only 3% and 1% Zn respectively (Table 4.12). In addition, the tin and lead contents also vary greatly, while only two objects consisted of a binary copper-zinc alloy of which only fibula M 1843.1 has a substantial zinc content of 9% Zn. Three objects (pin AE 86, ring AE 483 and wheel-disk pendant AE 427) have a tin content ranging from 3% to 10% Sn, with no further additions apart from the zinc which ranges from 1% to 6% Zn. Finally, another three objects (fibulae M 2122.2 and M 2226 and ring AE 721) have a 4-5% lead content on top of the tin (9% Sn mean) and the zinc (1.6% Zn mean) ones (Figure 4.26).

Typically, oreichalkos was not further alloyed, and it was rather left as a Cu-Zn binary alloy (Craddock 1978, p. 1). However, zinc-rich alloys containing as much tin and lead as ordinary bronzes suggest zinc's accidental presence which would have most likely been ignored by the metalsmith who treated the metal as an ordinary Cu-Sn(-Pb) alloy (Craddock and Eckstein 2003, p. 217). The latter is seen in the majority of the >1% Zn containing objects in the Pheraean assemblage in which tin and lead are added regardless the zinc content even when it is at 6% Zn. Admittedly, 1%-2% zinc content as found in six out of the eight zinc-rich objects is low enough to be described even as an impurity, whereas its presence would have been hardly noticeable either in the metal's colour or its physical properties. Meanwhile, variable amounts of additional elements can occur from recycling and mixing oreichalkos with already alloyed copper. Thus, tin, lead and/or arsenic can potentially occur if bronze, leaded bronze or arsenical copper are added to a copper batch naturally rich in zinc. Brasses with tin and lead additions have been known as early as the 14th century BC (1350 BC) as indicated by a group of rings from northern Iraq with 12% Zn together with various amounts of tin and lead, e.g. 12% Zn with 3% Pb and 6.3% Sn or 14.5% Zn with 5% Pb and 0.5% Sn (Christine Bedore in Bayley 1998, 8-9; Craddock and Eckstein 2003, 216).

Finally, fibula M 1843.1 singles out in the entire sample as the only object of a binary copper alloy rich enough in zinc (9% Zn) to be classified as a proper oreichalkos. Moreover, it is a unique find in the assemblage also due to its typology too. Due to its semi-circular, horse-shoe shape it is tempting to attribute it to the Anatolian fibulae tradition (Blinkenberg 1926, pp. 204–230, Birmingham 1961, Kilian 1975, pp. 154–157, pl. 59) (Figure 4.27). Thus, its typology could be reinforcing the possible trace the raw material and production to Anatolia. This would further reinforce the interpretation of oreichalkos as copper from the mountains, namely the mountains of Anatolia [mountain=όρος (oros) + copper=χαλκός (chalkos)].

Zinc-bearing copper ores in Greece and the Mediterranean have been said to possibly originate from the East where sulphidic copper ore sources that often contain traces of zinc have been documented in Cyprus and Anatolia (Key 1963, p. 290, Craddock 1978, p. 2). Early brasses have been documented within the Anatolian and western Asia region. Examples include artefacts from Ugarit in Syria with random zinc contents which were the result zinc bearing copper ore smelting (Muscarella 1967, Rehren 1999, Thornton *et al.* 2002, Thornton and Ehlers 2003). Reported brasses from Vounous Belapais in Cyprus by Stewart and Steward (1950) have been later found of arsenical copper with no traces of zinc as re-analysed by Craddock (1995, p. 293). Furthermore, zinc-bearing objects closer to the dating of Pheraean assemblage, included a group of 7th century BC fibulae from Phrygian tombs at Gordion in Asia Minor, an 11% Zn bracelet and several 2.6-11% Zn fibulae dated to the 8th and 7th centuries BC from Çavustepe in north-eastern Anatolia (Schaeffer-Forrer *et al.* 1982, Geçkinli *et al.* 1986). Finally, ancient literary sources including a number of Assyrian cuneiform tablets of the 8th-7th centuries BC also seem to reinforce the above theory for an eastern provenance of natural brasses (Halleux 1973, Bayley 1998, p. 8, Craddock 1998, pp. 3–4).

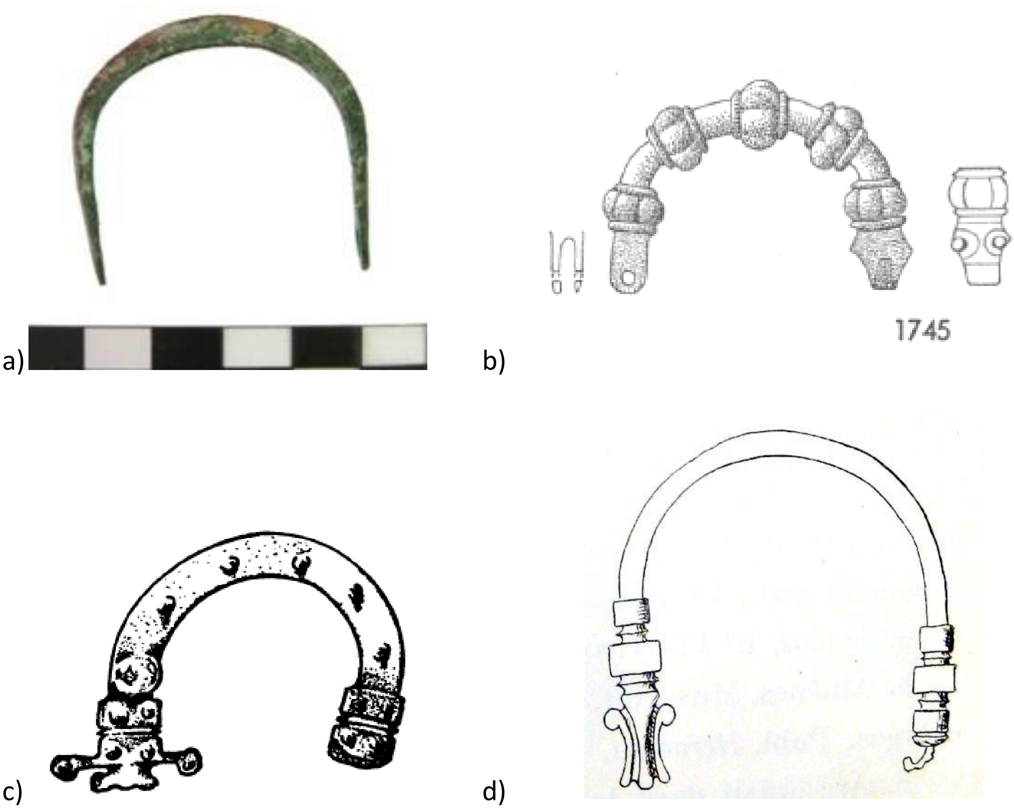


Figure 4.27. A) Brass Fibula M 1843.1 and drawings of Anatolian fibulae B) after Kilian (1975, pl. 59, 1745), C) after Birmingham (1961, p. 187, fig. 1) and D) after Blinkenberg (1926, p. 211, fig. 234)

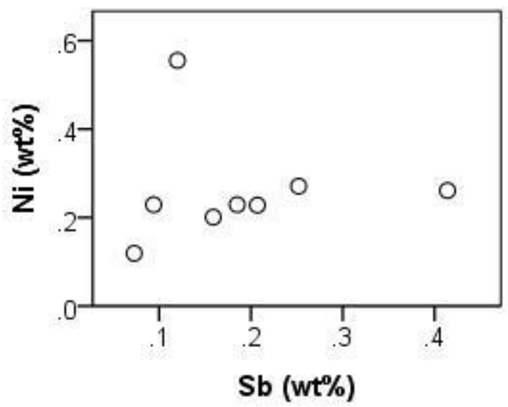


Figure 4.28. Scatterplot of antimony against nickel showing a correlation trend for the two elements in the whole of zinc-rich group (n=8)

Trace elements for the zinc-rich group showed no clear correlations or specific patterns, while this was partly expected due to the varied nature of the objects in this group. Nonetheless, the only possible positive correlation as noted between nickel and antimony. As previously argued for the unalloyed copper group, zinc-bearing objects are too few in the sample analysed here to come to any definite conclusions about trends and correlations in the trace element concentrations that would indicate a technological connection between the artefacts.

Overall, the varied typology and chemical composition of the zinc-rich group do not suggest either a single production centre or a common origin for the raw materials. However, they do indicate the presence of copper alloys with variable zinc contents in mainland Greece during the first half of the 1st millennium BC, either as the result of importing oreichalkos objects (fibula M 1843.1) and remelting and recycling oreichalkos heirlooms in order to produce new batches of bronze, or circumstantially through smelting of naturally zinc-rich copper ores under reducing conditions.

Chapter 5. Minor and trace elements and the quest for tradition

Ancient copper, as all metals, contains a number of minor components in various concentrations and ratios that are best described as natural ingredients, as opposed to alloying elements (as discussed in Chapter 4). Impurities may be present as traces (below 0.1% or at the ppm level, i.e. 0.0001%) or even at the percent level, while they can also be unwelcome or sought after additions to copper metal as it has been, for example, argued for the emergence of the first bronzes and brasses (oreichalkos) when naturally occurring tin- or zinc-rich copper ores were preferred for their physical properties and/or colour (e.g. Radivojević *et al.* 2013). The effect these impurities had on copper would have been proportionate to their concentration. Meanwhile, ancient smiths would remove unwanted impurities from copper following a refining process, starting with repeated remelting.

These components are a reflection of the ore mineralogy and the physical and chemical processes that they undergo during primary production or any subsequent metalworking steps involved in the metal object production (Goffer 2007, p. 43, Pollard and Heron 2008, pp. 193–4). Copper metal alone already contains a number of additional elements in variable concentrations but typically below 1% which largely depend on the initial composition of the minerals employed, the smelting and beneficiation processes, and metalworking treatments including remelting and recycling of metal (Tylecote *et al.* 1977, Pernicka 1999, Bray and Pollard 2012). As a result, several elements are present in the metal produced that reflect both geological and technological parameters. Overall, trace and minor elements are the result of unintentional events rather than the smiths' and metalworkers' conscious decision making, whereas they can additionally be affected by preservation conditions such as corrosion products and soil chemistry in the case of ancient buried metal artefacts (Tylecote 1979, Gerwin *et al.* 1998). For instance, concentrations of lead, iron or arsenic at above 1% have been often reported in ancient copper objects as a result of lead-, iron- or arsenic-rich copper ores. Potentially, these elements can be also present in concentrations well above 1% or 2%. Lead content, for example, of up to 10% or 15% can still be the result of lead-rich copper ore smelting due to its often co-occurrence with copper in both oxide and sulphide mineralisations used in antiquity (Farquhar and Vitali 1989, p. 38), whereas the same is true for zinc (see also Chapter 4.2.4). Similarly, experiments have suggested that arsenical copper with up to 5% arsenic content could have been obtained by direct smelting of Cu-As ores by Andean metalworkers (Lechtman 1996, Earl and Adriaens 2000).

5.1 Trace elements in ancient copper

5.1.1 The impact of trace and minor elements on ancient copper

Minor natural ingredients in ancient copper had various impacts on the metal's properties which strongly depended on the nature of the elements themselves, as well as on their respective concentrations. Most of the trace elements present in copper and its alloys would typically be of little financial or cultural importance as they would have no or little effect on the finished object's physical or chemical properties particularly when found at the ppm (parts per million) level. However, certain minor elements could have a more pronounced effect on the metal's working properties such as its ductility and hardness. For example, even though a couple percent of tin or lead in copper would not have had any significant impact on its working properties or appearance when it came to ancient metal production standards, arsenic at the same levels would have altered copper's colour and hardness to the extent that the metal would be better described as a natural alloy (Northover 1989b), while iron would have rendered it rather brittle. A metal clean of impurities or with a silvery or golden tint, such as a natural alloy with just a few percent of arsenic or zinc respectively, would potentially have been positively received by the market in which precious and good quality metal objects with a characteristic metallic lustre would have been appreciated and sought after. Finally, any unwelcome minor ingredients in copper would have been partially removed by refining of raw copper starting with repeated remelting (Tylecote *et al.* 1977).

5.1.2 Trace element analysis: potentials and limitations

The first attempts in the history of archaeometallurgy to determine the trace element concentrations of ancient metal objects took place in the 1930s (Pernicka 2014b). Apart from the technological advances in analytical chemistry which allowed the detection of elements at the ppm level as, for example, by means of atomic emission spectroscopy (AES), these efforts were also triggered by the founding principle that characteristic trace element fingerprints of specific ore bodies would have been passed on to the finished objects whose analyses would contribute in their provenancing (Pollard and Heron 2008, p. 193). However, the relationship between the trace element fingerprints of ore bodies and objects in antiquity is a complex one as it can be affected by numerous parameters. Thus, the assumption that all finished objects produced from the same ore body would have identical trace element fingerprints is almost a 'naive' one since numerous factors in the various production stages determine the trace element concentrations of the finished objects (Gale and Stos-Gale 1982, Budd *et al.* 1996, p. 168). Finally, the provenance hypothesis would only be valid if all objects were made from a single ore and following the exact same techniques and redox conditions during all production stages.

Conversely, and as indicated by smelting experiments (e.g. Tylecote et al. 1977, Wang and Ottaway 2004) the presence of these accidental minor components, would have been affected by reduction and partitioning during smelting and refining, but also by mixing, recycling, and alloying strategies which routinely took place during antiquity. Standard crucible refining, for instance, would suffice to dramatically alter the trace element pattern of copper metal (Tylecote *et al.* 1977, p. 320), while the practice of recycling and mixing of fresh and scrap metal which was already practiced from the Bronze Age (Karageorghis and Kassianidou 1999). Last but not least, compositional variation can take place even within a single ore body or region, whereas different geographic locations can also provide similar trace element patterns (Begemann *et al.* 1989, Sayre *et al.* 1992, p. 83, Chapman 1996, p. 79). Finally, determining the provenance of a given copper from a certain ore body is not a straightforward task statistically either (Bowman *et al.* 1975, p. 161).

technology	provenance and/or technology	provenance
Al, *B*, Ba, *Be*, *Ca*, **Cr**, *Cs*, **Fe**, *Ga*, *Ge*, Hf, *K*, *Li*, *Mg*, *Mn*, Mo, *Na*, *Nb*, *P*, Rb, *S*, Sc, REE[b], *Si*, *Sr*, Ta, *Ti*, Th, U, *V*, *W*, *Y*, Zr	**As**, **Cd**[a], **Co**, In, **Hg**[a], Re, **Sb**, **Se**, **Te**, *Tl*[a]	**Au** **Ag**, ***Bi***, **Ir**, **Ni**, Os, Pd, Pt, *Rh*, Ru
Sn > ca. 1% **Zn** > ca. 5% ***Pb*** > ca. 5%	**Sn** < ca. 1% **Zn** < ca. 5% ***Pb*** < ca. 5%	

Figure 5.1. Trace elements in ancient copper characteristic for the provenance of raw material and/or the technology of the finished object (Pernicka 1999, p. 170); Tylecote et al. (1977, p. 323), though, mention that nickel and bismuth are potentially affected by refining of copper

Despite the above limitations, the study of copper-based objects trace element fingerprints can shed light on certain aspects of the their production cycle and their life histories from raw material provision to subsequent technological steps and final disposal (Pernicka 1999, Bray and Pollard 2012) (Figure 5.1). It has been also argued that certain trace elements would have been affected in different ways during production which can prove as more reliable signifiers of ore geology and/or technological practices than others. For instance, it has been shown that trace elements such as gold or nickel would have been affected to a lesser extent by the metallurgical practices in relation to other elements such as iron or arsenic (Pernicka 1999). Since, it is during ore and metal processing and the characteristic operating thermodynamic and redox conditions that the metal objects' trace element fingerprints are defined, it follows that investigation of trace elements and impurities in metal objects can be informative of the metal objects' technology (Pollard and Heron 2008, pp. 193–194). Thus, trace elements analysis can rather contribute in reconstructing the technological process than in their geological provenancing. Finally, trace element analysis can also provide insights into distinct metallurgical traditions, treatments and techniques employed within metal object assemblages.

5.2 Trace element analysis of the Pheraean bronzes

Discussion of the trace element concentrations in the Pheraean assemblage took into consideration the above limitations, as well as the nature of the analytical methodologies as discussed above (see Chapter 3). Due to comparability issues of the analytical instruments and their different minimum detection limits, the EPMA results are primarily discussed below, whereas the pXRF data will be presented mainly for comparison.

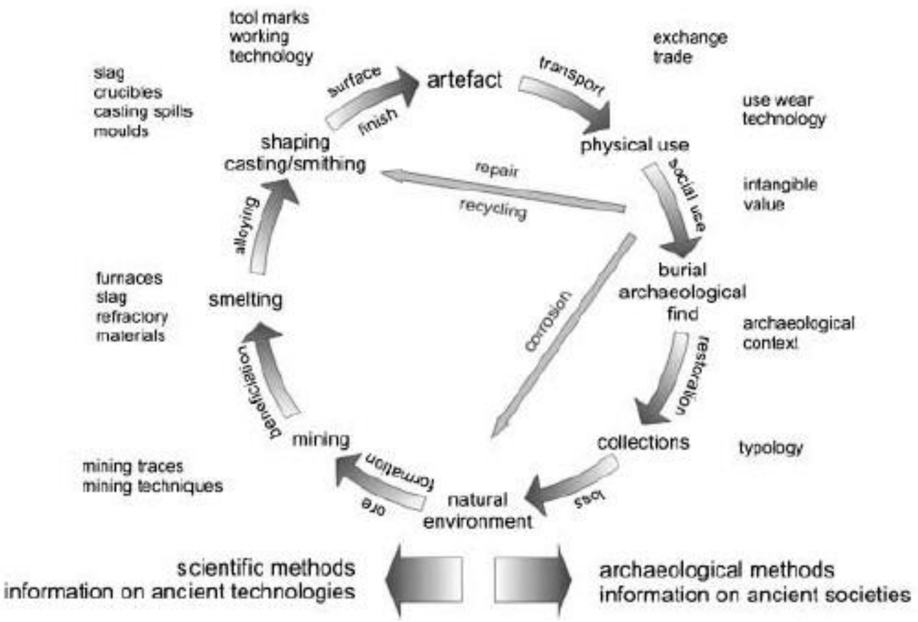


Figure 5.2. The archaeometallurgy cycle (Ottaway 1994, n. after Rehren and Pernicka, 2008, p. 233)

The Pheraean assemblage was the accumulative result of a long metallurgical tradition involving high degree of heterogeneity and diversity both in raw materials and metallurgical technologies. Thus, the examined artefacts would not have been the product of a single smelting episode, but rather of multiple operations taking place in workshops both spatially and/or chronologically distanced. They were also part of a metallurgical tradition when recycling and mixing of metals would have been a well-embedded mainstream technological step integrated in the production cycle (Figure 5.2). This is reflected in the archaeological record of Early Iron Age Greece and eastern Mediterranean where tin bronzes were the norm, as opposed to unalloyed copper as also illustrated in the results of assemblages from mainland Greece including the sites of Kalapodi and Nichoria (for a more detailed discussion of comparative material from Early Iron Age mainland Greece see Chapter 8). In fact, out of the whole sample analysed from Kalapodi (approx. 150 objects), only ten objects have been found of unalloyed copper with lead and tin only present at impurity levels (Felsch 2007, pp. 406–407). Analyses from Nichoria further add to the above pattern and support the marked decrease of unalloyed copper objects in the transition from the Bronze to the Iron Age (Figure 5.3) (Rapp *et al.*

1978, p. 170). Hence, the focus of this analysis is not the actual geographic/geological provenance of the metal(s) used to produce the artefacts deposited to the sanctuary of Enodia, but rather the investigation of technological aspects that would shed light on the Early Iron Age bronze-smith's repertoire, namely the metalworking traditions, metal quality and manufacturing techniques.

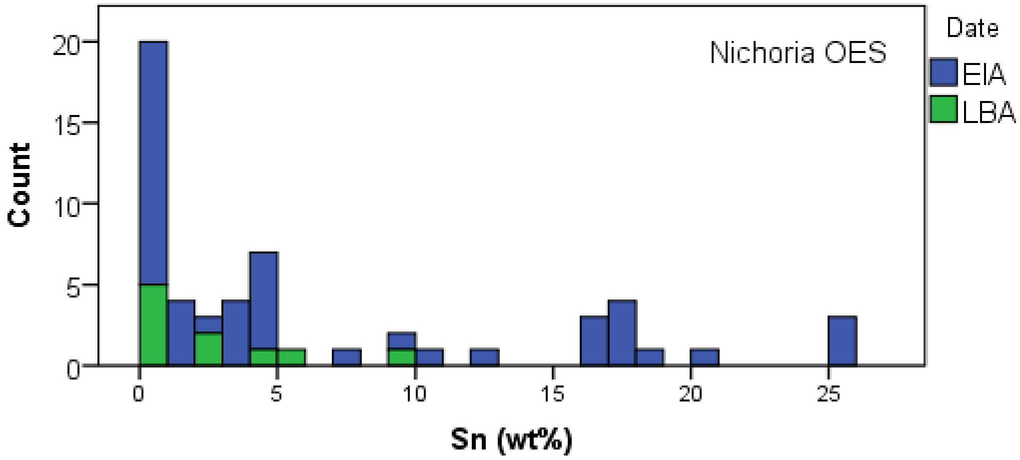
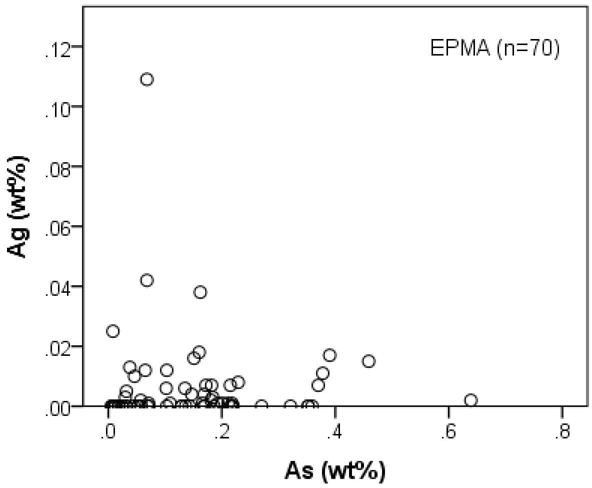


Figure 5.3. Histogram of tin distribution in LBA and EIA copper-based objects (n=46) as analysed with OES from Nichoria (after Rapp et al. 1978)

a) 

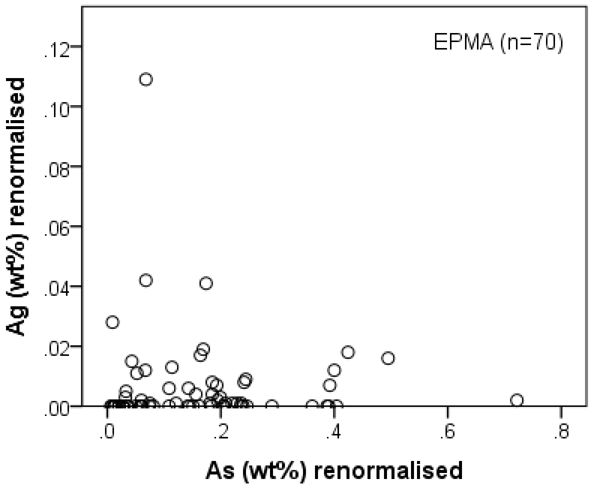
b) 

Figure 5.4. Scatterplots of arsenic against silver for the EPMA dataset before (A) and after (B) recalculation where an identical pattern is visible

5.2.1 Results

During EPMA-WDS examination a set of 14 trace elements was analysed including Se, Zn, Ag, As, Fe, S, Bi, Co, Sb, Ni, Mn, and Pb, whereas oxygen and chlorine were also analysed as a means to establish the degree of corrosion on the samples. In order to examine the relationship between copper and the trace element concentrations, EPMA results were recalculated and renormalised after the tin content was subtracted from the totals following the principle that most impurities would come from the copper rather than the tin ores. This would allow a deeper exploration of the impurities in copper used for the production of the Pheraean offerings as it provided a platform for comparison across different alloy recipes such tin bronze and leaded bronze. Nonetheless, comparison of normalised (raw data) and renormalised (after tin subtraction from totals) for all elements showed an almost identical pattern as characteristically illustrated in the arsenic against silver scatterplots (Figure 5.4). Due to the above overall rather unnoticeable differences in the EPMA d above feature of the assemblage, EPMA normalised raw data are discussed below.

Table 5.1. Summary table of trace and minor elements in the Pheraean assemblage for the EPMA analysis (n=70, wt%)

Case Summaries: EPMA

	Se	Zn	Ag	As	Mn	Pb (<4%)	Sb	Ni	Co	Bi	S	Fe
Mean	.021	.000	.006	.145	.003	.405	.077	.067	.028	.011	.031	.145
Median	.015	.000	.001	.132	.003	.079	.057	.030	.005	.008	.021	.072
Min	.000	.000	.000	.005	.000	.000	.003	.005	.000	.001	.000	.000
Max	.112	.000	.109	.639	.009	3.257	.519	.455	.390	.051	.121	1.134
Skew.	2.7	-	5.3	1.4	1.1	-	3.2	3.0	4.1	2.4	1.3	2.7
Kurtosis	7.1	-	33.5	2.5	2.8	-	14.7	8.1	15.9	5.9	1.2	8.3

Table 5.2. Summary table of trace and minor elements in the Pheraean assemblage for the pXRF analysis (n=212, wt%),

Case Summaries: pXRF

	Zn	As	Pb <4%	Sb	Ni	Fe
Mean	.43	.31	1.09	.15	.19	.85
Median	.29	.24	0.70	.11	.18	.61
Min	.17	.12	0.00	.07	.07	.10
Max	9.28	2.35	3.99	1.30	.56	5.19

In the EPMA dataset all impurities were found at trace element levels (Table 5.1). Meanwhile, the same is true for the pXRF dataset with the exception of higher values on average for arsenic, iron, antimony, zinc, and lead primarily due to methodological concerns (Table 5.2) (see Chapter 3). However, it is argued that the two datasets are comparable to a certain degree when it comes to the elements' distribution patterns as opposed to absolute values. For example, both methodologies provided the same pattern for most trace element concentrations such as iron, arsenic or lead of positive, heavy-tailed distributions (Figure 5.5). This pattern with high levels of skewness and kurtosis is characteristic for trace elements in copper and reflects their accidental presence as natural ingredients depending on the nature of the raw material and the technological process involved as opposed to that of normal (symmetric) distribution which would point to their deliberate addition. Positive skewness for all trace elements suggests their concentration in values closer to zero, whereas the greater the kurtosis value is the pointier and heavier-tailed the distribution is too (Field 2009, p. 138).

5.2.1.1 Iron

Iron is amongst the commonest trace elements in ancient copper and copper-based objects (Jenkins 1989), as it is present in most copper mineralisations which upon smelting would still retain some iron (Rehren *et al.* 2012, p. 1724). Even in good quality ancient copper some iron would still be present which could be lowered through further metal refining (Tylecote *et al.* 1977, p. 305). Even though iron has been occasionally found in archaeological bronzes as a major element with contents of up to 40% (Craddock and Meeks 1987), it is most often present as an impurity with levels typically well below 1%. It has been suggested that unrefined, raw copper following smelting would still retain an iron content between 0.3-3.0%, while this could be even halved after additional beneficiation of the metal (Tylecote *et al.* 1977, pp. 313–314).

Removal of excess iron contents in ancient copper would have been desired since just a few percent of iron can have a significant impact on the metal's physical properties such as by making it prone to cracking and difficult to work, hammer and shape (Tylecote *et al.* 1977, Craddock and Meeks 1987). Furthermore, high iron contents in copper would have affected objects' appearance, as well as they would have triggered faster degradation rates as iron in copper/bronze tends to promote corrosion processes that would have altered the metal's colour and the loss of the characteristic bright metallic shine of bronze (Tylecote 1992). Due to the above, iron is an indicator often used to evaluate the overall quality of copper and its alloys.

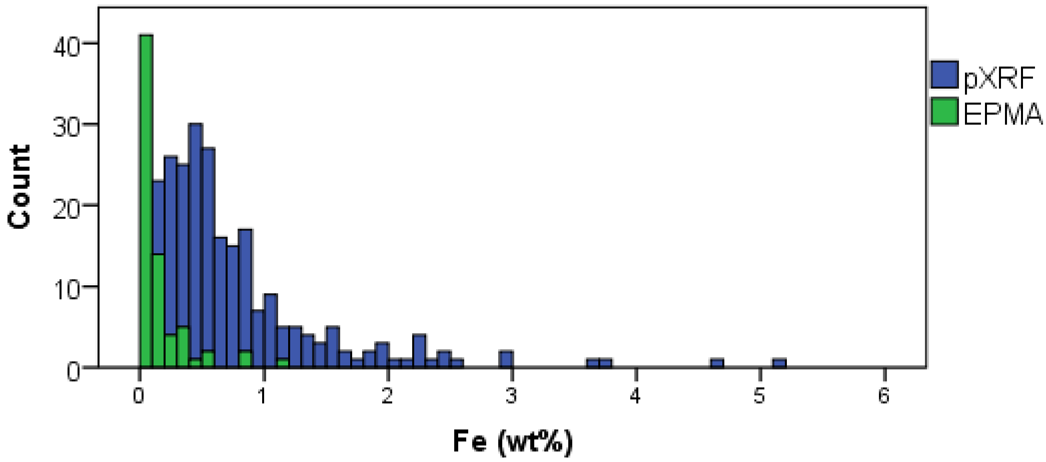


Figure 5.5. Histogram of iron distribution for the iron content in the assemblage for the EPMA and pXRF datasets; absence of iron values <0.1% for the pXRF dataset are linked to a false signal detected by the instrument

Iron in the sample was found with mean concentrations of 0.15% and 0.9% for the EPMA and pXRF datasets respectively, and median values of 0.08% and 0.7% iron for EPMA and pXRF (Figure 5.5). Higher average values, absence of values below 0.1% iron, and iron-rich objects with up to 5-6% iron as detected with the pXRF could be either the result of a false signal being detected by the instrument which produced results with artificially higher values or of corrosion processes and soil contamination on the objects' surfaces (Scott 2012, p. 196). Even if a thin layer of surface corrosion, i.e. patina, was mechanically removed, areas of analyses could have still been affected by corrosion not visible to the naked eye and/or by additional degradation phenomena that could have enriched the objects' substrate in iron. EPMA analysis point to an overall quite clean metal as four in five objects, i.e. 80% of the entire assemblage (227 out of 282 objects) contained <1% iron, while the same percentage escalates to 99% for the EPMA dataset (69 out of 70 objects). Moreover, EPMA values for iron even towards the high end of the spectrum are not larger than 1% Fe.

Iron concentrations in the sample match many of the already published analyses of copper-based assemblages from mainland Greece including Kalapodi with average and median values of 0.6% and 0.2% Fe, as well as assemblages from other sites in the eastern Mediterranean and Near East such as Late Bronze Age Timna and Early Iron Age South Italy (Craddock 1977, 1980, Riederer 2007) (see also Chapter 8). Overall, iron content in the assemblage analysed with both methodologies points to a pattern of accidental presence of the element as an impurity from the raw materials used, whereas the typically low levels of iron suggest the practice of repeated refining steps.

5.2.1.2 Arsenic and Zinc

Arsenic and zinc are common trace elements in ancient bronzes and, as with iron, are often found in ore bodies in association with copper minerals. Nonetheless, they are rarely found in significant quantities as their contents would have been lost through evaporation during each subsequent metallurgical step from roasting and smelting to casting and annealing in oxidising conditions (Craddock 1976, p. 94). Therefore, their content would be always lowered with of an object, as long as it took place under oxidising conditions. Additionally, the loss of these elements would have also been time- and heat-dependent, namely the longer they were heated and the greater the temperatures involved, the greater their loss would have been (Tylecote *et al.* 1977, p. 314, Tylecote 1992, pp. 20, 25). Arsenic concentrations in ancient copper can be drastically altered and lowered by working techniques too (McKerrell & Tylecote, 1972), while such impurities are potentially introduced to copper via the smelting of a gossan flux, i.e. the upper and exposed part of an ore deposit, or even by the addition to the melt of arsenic-rich minerals (Tylecote *et al.* 1977, pp. 317–319, Rehren *et al.* 2012).

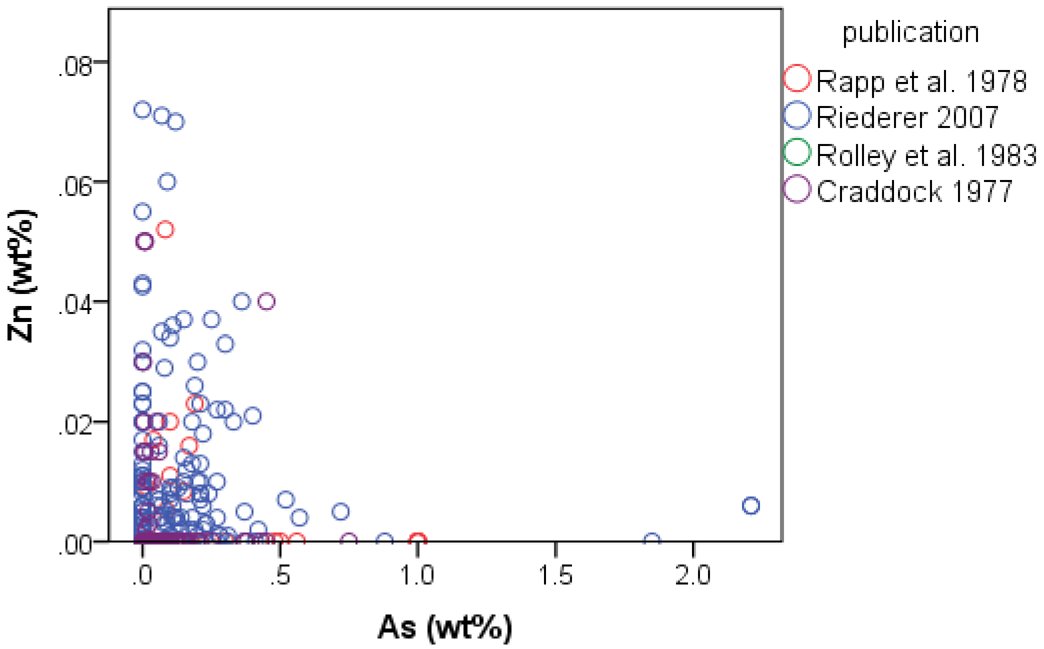


Figure 5.6. Scatterplot of arsenic against zinc for the assemblages analysed by Craddock (1977), Rapp et al. (1978), Rolley et al. (1983), and Riederer (2007)

Zinc traces, as with arsenic, are often found in association with ancient copper. Nonetheless, zinc-rich copper ores are more difficult to find and noticeable zinc contents in Early Iron Age copper and bronze from Greece and the Aegean are often found in imported objects. Anatolia, for example, has been well known during antiquity for its 'golden copper' or oreichalkos, namely a natural brass resulting from smelting of zinc-rich copper ores (Thornton, 2007). This pattern for the arsenic and zinc contents can also be seen in already analysed assemblages from Early Iron Age Greece such as the mixed assemblages from Kalapodi and Nichoria (Rapp *et al.* 1978, Riederer 2007), as well as the assemblages of statuettes/decorative articles/armour and tripods analysed by Craddock (1977) and Rolley *et al.* (1983) respectively. All these EIA assemblages from mainland Greece and the Aegean showed low average arsenic and zinc contents with values of 0.5% As and <0.1% Zn respectively (Figure 5.6).

Table 5.3 Compositions of objects containing >1% arsenic in the sample (n=5; n.a., not analysed)

Inv.No.			Cu	Sn	Pb	Zn	Fe	Ni	Ag	Sb	As
M 4418.5.2	tweezers	pXRF	88.9	6.0	0.0	0.3	1.0	0.1	*n.a.*	1.3	2.3
M 1877	fibula	pXRF	85.9	9.9	0.0	0.4	2.0	0.2	*n.a.*	0.3	1.3
AE 936	ring	pXRF	93.5	3.0	0.6	0.3	0.2	0.1	*n.a.*	1.0	1.2
AE 585	fibula	pXRF	92.2	3.5	0.8	0.3	1.6	0.3	*n.a.*	0.2	1.2
AE 116	object	pXRF	97.0	0.6	0.0	0.3	0.7	0.2	*n.a.*	0.1	1.1

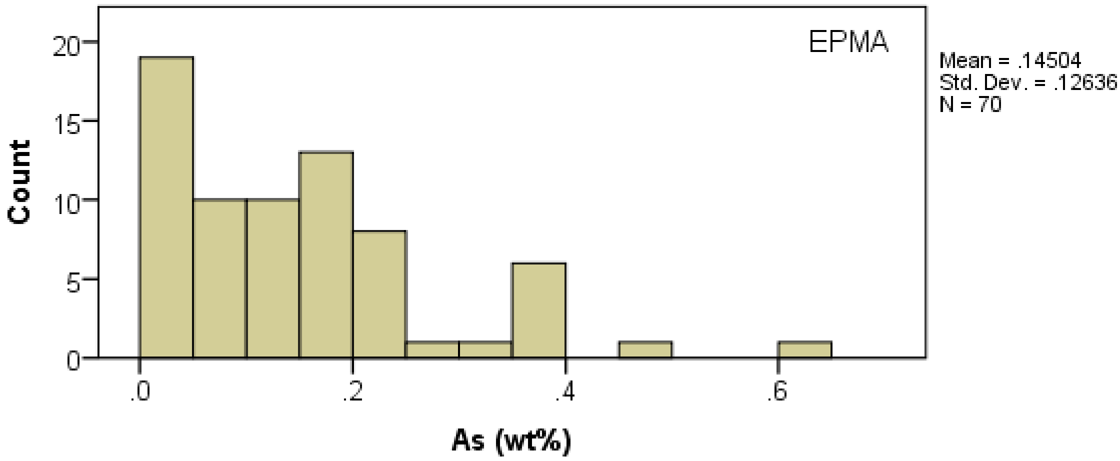


Figure 5.7. Arsenic content distribution as analysed with the EPMA (n=70)

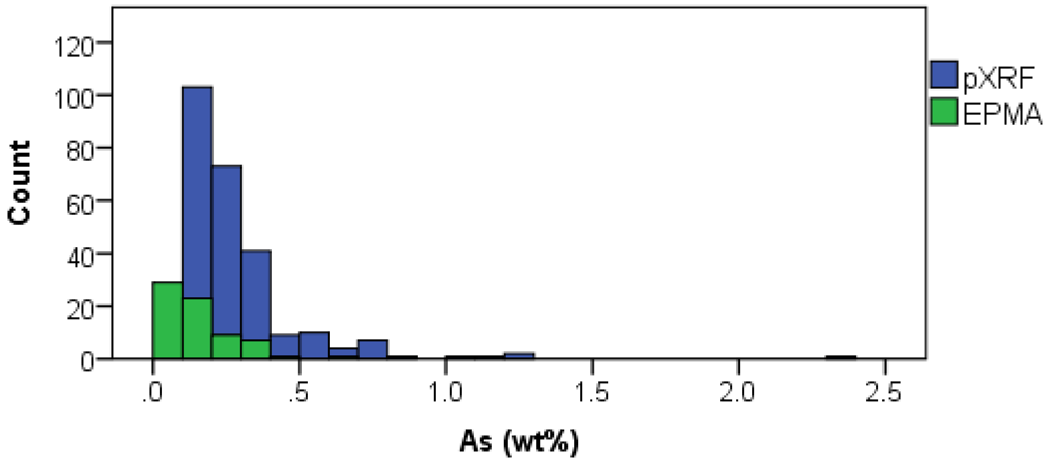


Figure 5.8. Arsenic distribution in the EPMA and pXRF datasets; lower values are seen in the EPMA, whereas absence of pXRF values <0.1% As has to be attributed to the detection limit of the instrument

In the analysed sample, both zinc and arsenic were found as impurities in the vast majority of the objects (for a discussion of zinc-rich samples see Chapter 4.2.4), while EPMA and pXRF values presented certain differences, as also noted for iron above. Higher arsenic and zinc values detected during pXRF analyses, as in the case of iron (see above), are the result of a false signal detected by the instrument are not considered as reflections of the object composition (Figure 5.8). EPMA results for arsenic with an average of 0.16% and maximum value of 0.64% suggest its presence strictly as accidental (Figure 5.7). With 98% of the pXRF sample containing arsenic below 1% (207 objects, both datasets), only a handful of artefacts were found with arsenic to suggest technological links with the metallurgy of arsenical copper.

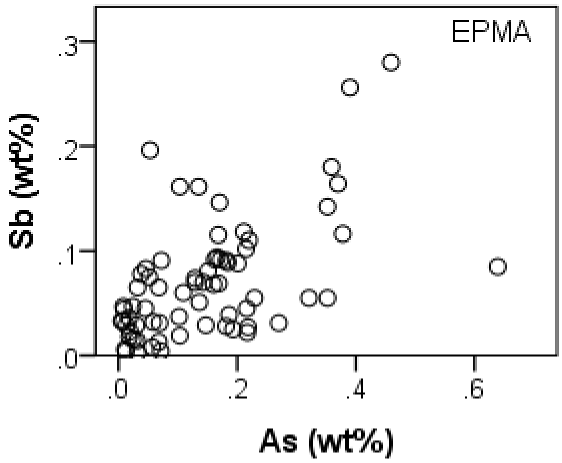


Figure 5.9. Scatterplots of arsenic against antimony for the EPMA dataset where a positive correlation is visible

Five objects have been found with arsenic between 1% and 2% as analysed with the pXRF (Table 5.3). Even though arsenic is easy to lose through evaporation upon heating to 887^{o} C, it is quite difficult to remove from copper completely by employing methods that would have been available to ancient metallurgists (Rehren *et al.* 2012, p. 1724). Thus, even upon repeated remelting arsenical copper would still retain some of its initial arsenic content which would have been depleted upon repeated remelting (Bray and Pollard 2012), but would not have been completely lost (Bassiakos pers. com.). Arsenic-rich objects could have been the remnants of an earlier metallurgical tradition as, for example, seen in a group of Early Iron Age pins from Lefkandi (Orfanou 2009). In the majority of the arsenic-rich objects as analysed with the pXRF, tin has been added in various concentrations, whereas two out of five objects contain 1% antimony which could further support the presence of arsenic as an impurity as suggested by Craddock (1976, p. 104). Additionally, the relationship of arsenic and antimony in the EPMA dataset points to a positive correlation (Figure 5.9). Moreover, arsenic content is not related to any other alloying element, namely tin or lead, suggesting that alloying of copper took place irrespective of the arsenic content. Finally, arsenic-rich artefacts, as with zinc-rich ones (see above Chapter 4, Table 4.12), belong to different artefact types and they do not form a coherent group neither typologically nor compositionally.

Taking into consideration the nature and characteristics of the zinc- and arsenic-rich artefacts in the assemblage from Pherae it is difficult to argue for a distinct, deliberately alloyed group of objects within the Pheraean assemblage. Meanwhile, there is evidence to suggest that these minor additions passed unnoticed by the metalsmiths and they should also not be taken as indications of a common origin, provenance, chronology, and metallurgical tradition, but rather as technologically circumstantial, namely it cannot be argued that all arsenic-rich objects have a common origin either geological or technological.

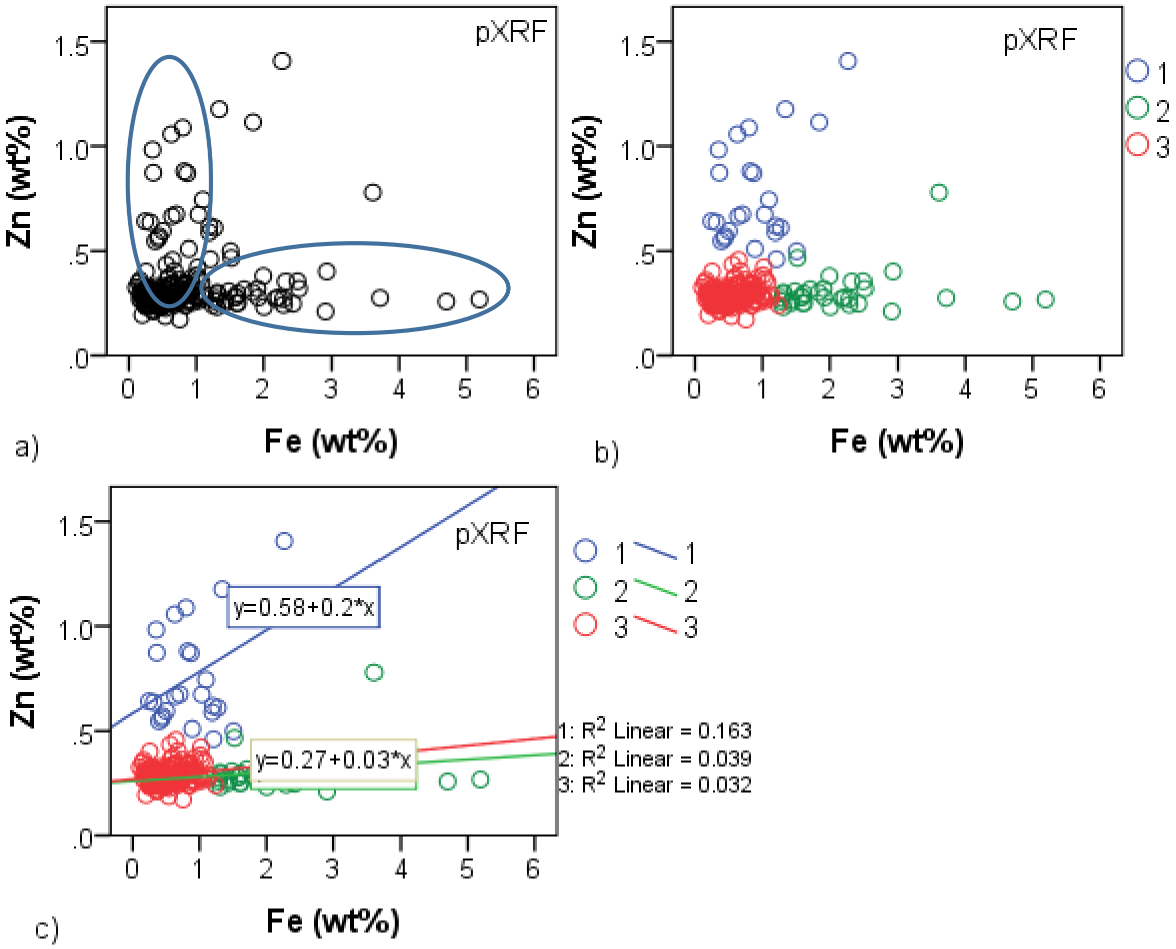


Figure 5.10. Scatterplot of zinc against arsenic for the pXRF dataset where three compositional groups (0.7 significance) are visible (B); a positive correlation for group 1 is also visible (C)

Finally, a rather positive correlation between zinc and iron for the artefacts with >0.5% zinc could be taken as evidence for the presence of these zinc levels detected with the pXRF as a result of surface deterioration (Figure 5.10a-c). This is further supported by corroded samples analyses as, for example, zinc-rich fibula M 3367.2 with 3% Zn and minor concentrations of tin and lead (3% Sn and 0.6% Pb) which also contained iron levels of 39% Fe. This strongly suggests that analysis took place on corrosion layers and it did not reflect the composition of sound metal (this fibula, as with the rest of the corroded objects, has not been included in the discussion of results). This fact is a strong indication of how corrosion phenomena can affect the original composition of the copper-based objects towards their surface.

5.2.1.3 Antimony

Antimony is also an element often found in association with copper ores and, thus, it is typically encountered as an impurity in ancient bronzes. As with elements discussed above such losses of naturally occurring antimony in copper would potentially occur during metal production and metalworking (McKerrell and Tylecote 1972, Tylecote et al. 1977). In the Pheraean assemblage, apart from a typical trace element distribution for antimony with a mean value of 0.07% in the EPMA dataset, a positive correlation of antimony with sulphur and arsenic is also visible which further supports the association of both of these elements' values and their reduction through the sequence of metalworking practices (Figure 5.9). Finally, only ring 1310 is antimony-rich with a content of 0.5% which is also bismuth-rich (see this Chapter 5.3.1.6) as analysed with the EPMA was found in the assemblage (Table 5.7).

5.2.1.4 Sulphur

Sulphur is commonly found in ancient copper and is largely characteristic of primary sulphidic ore smelting as would have been expected for the context of 1st millennium BC when most of the oxidised ores and native copper would have been exhausted. Sulphur was analysed only with the EPMA and it has been consistently found in values to suggest the use of sulphidic copper ores. Mean and median values are 0.03% and 0.02% S respectively whereas sulphur was detected in all samples with a single exception (Figure 5.11). Ring AE 856 (Type III, see Appendix I) is the only object whose analyses showed no sulphur. However, taking into consideration that both samples cut from this sheet ring were severely corroded and that only specks of sound metal survived in a corrosion matrix of cuprite and copper salts close to the object's surface, depletion of sulphur could have been caused by corrosion processes (Figure 5.12).

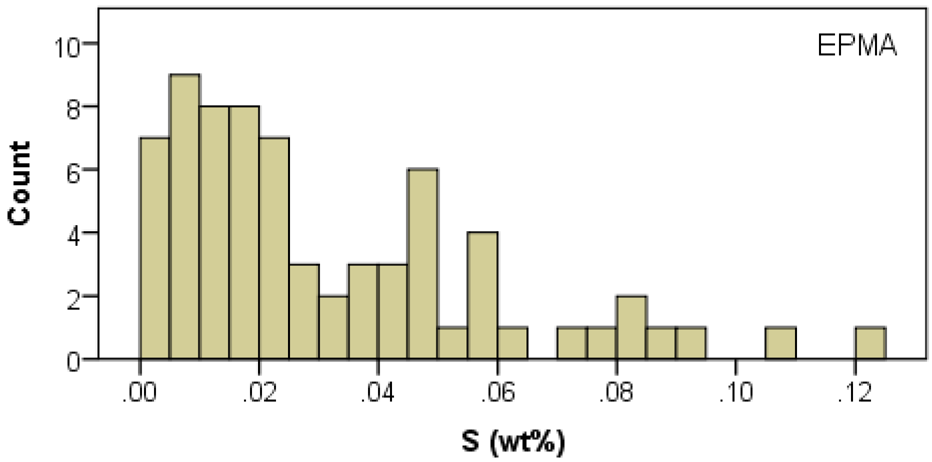


Figure 5.11. Sulphur distribution in the EPMA sample (n=70)

The sulphur inclusions have been also noted microscopically in all 70 samples examined, (Figure 5.13). Sulphide inclusions exhibited differences in their size and/or shape that would depend on the metalworking treatments practiced. Observation of these inclusions provided evidence for the different metalworking techniques employed in the production of the copper-based artefacts. For example, hammering and mechanical stress applied on the metal object would have distorted the sulphide inclusions by giving them an elongated or angular shape.

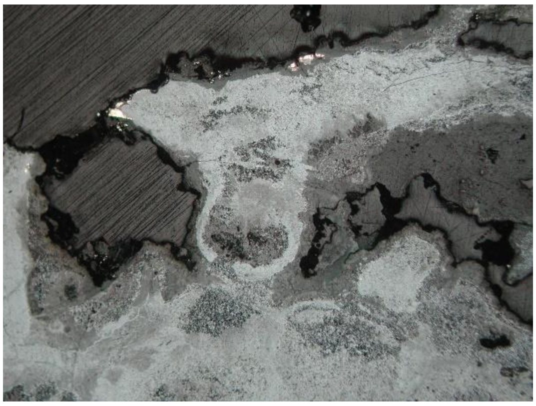


Figure 5.12. Photomicrograph of ring AE 856 where specks of sound metal are visible close to the surface surrounded by corrosion products; PPL, 50x, image width 3.5mm

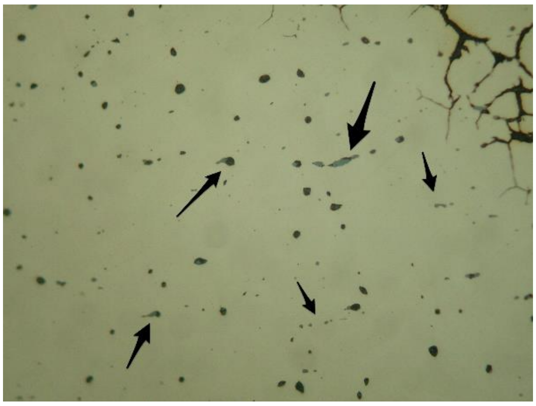


Figure 5.13. Photomicrograph of ring AE 597 where sulphide inclusions are visible (black arrows); PPL, 500x, image width 300µm

5.2.1.5 Tin and lead

Despite that tin and lead are the main alloying agents and the only deliberate additions to copper in the Pheraean assemblage (see Chapter 4), they have also been detected at levels to suggest their accidental presence in the copper. Here, tin <1% and lead <4% have been considered as accidentally present in the copper either from tin- and lead-rich ores or from recycling and mixing of scrap bronze and leaded bronze with copper. Tin at impurity levels has been found in only two objects as analysed with EPMA with values of 0.01-0.03% Sn, whereas the vast majority of the EPMA sample (65 objects) has been found to contain lead at impurity levels (<4% Pb).

For the lead content, in particular, different thresholds for its addition have been adopted in archaeometric studies ranging from 1-1.5% (Gale and Stos-Gale 1982, p. 13, Chikwendu *et al.* 1989, p. 30) to 4% Pb (Pernicka *et al.* 1990) and even 5% Pb (Pernicka 1999) (Figure 5.1). Due to lead's mineralogical and physical properties, and its often co-occurrence with copper ores such as in Rio Tinto, a value towards the high end of this range has been adopted in the present study as a safer choice for distinguishing natural alloys from leaded copper and bronze ones. In addition, it has been taken that the tin added to copper is essentially lead-free since cassiterite deposits in Precambrian rocks are typically lead-free (Gale and Stos-Gale 1982, p. 13).

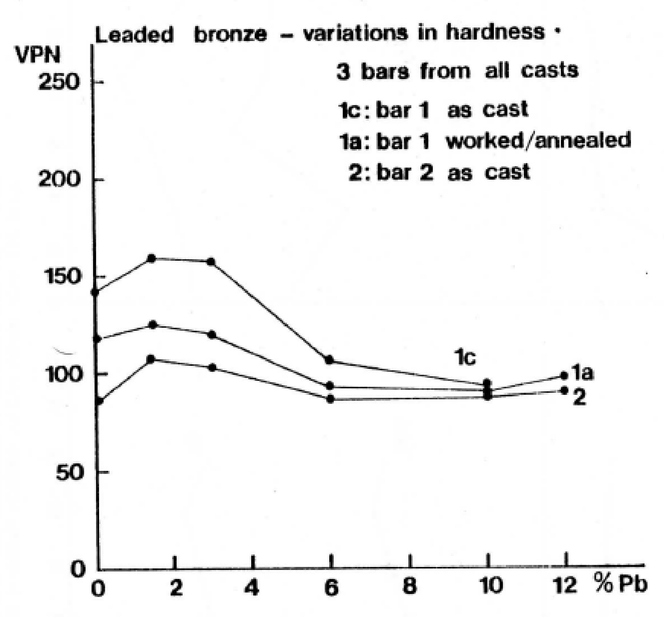


Figure 5.14. Graph of lead content in bronzes against hardness rates where similar hardness is visible for leaded bronzes >4% Pb (after Staniaszek and Northover 1983, p. 271, fig. 7) (VPN= Vickers Pyramid Number)

Even though, tin and lead would both enhance copper's properties at concentrations of deliberate alloying, small amounts of these elements could still have a noticeable impact on the copper produced, i.e. the metalworking processes involved and the finished objects alike. For instance, tin and lead in copper have an effect on the metal's corrosion rate. On the one hand, tin as a more noble metal acts as a corrosion resistant agent in copper alloys, whereas, on the other, lead can have the opposite effect under certain burial conditions such as alkaline and organic rich soils (Tylecote 1979, p. 351, 1983, p. 407). Furthermore, it has been argued that additions as little as 0.1% to 0.2% Pb would have given a characteristic shine to cast copper (Tylecote 1992, p. 111), whereas lead concentrations above 2-3% Pb would have have sufficed to reduce the hardness of a 2% tin bronze (Wang and Ottaway 2004, pp. 64–65). On the contrary, hardness of binary bronze tends to increase substantially with even tin additions of 2% (op. cit.). Furthermore, experiments have indicated that 2% lead in copper would have enhanced the metal's castability and machinability (Staniaszek and Northover 1983, p. 265) (Figure 5.14). Even though the aforementioned effects of tin and lead on copper are more markedly noted in higher concentrations, they would still have a substantial impact on bronzes with tin and lead contents below 4%.

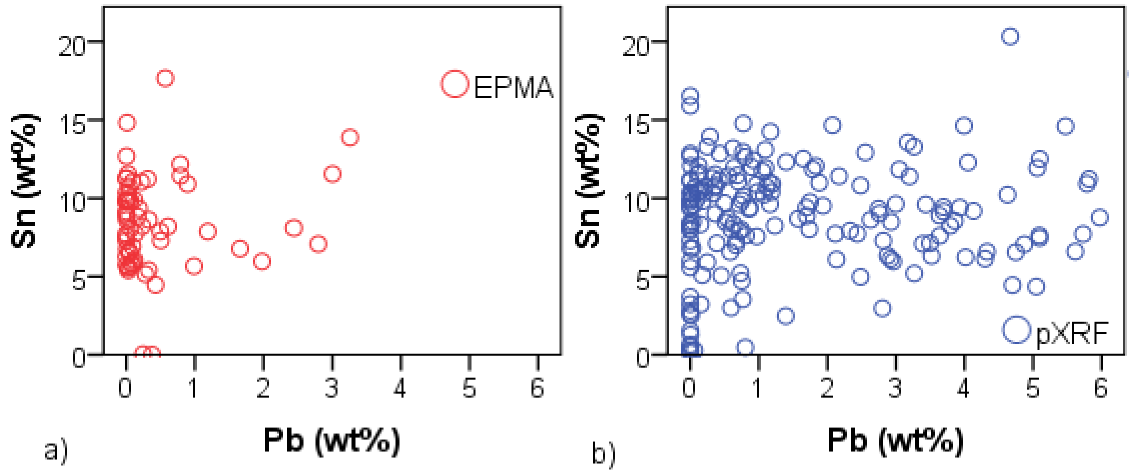


Figure 5.15. Scatterplots of lead at impurity levels against tin for the (A) EPMA and (B) pXRF datasets where a similar pattern is visible in both datasets

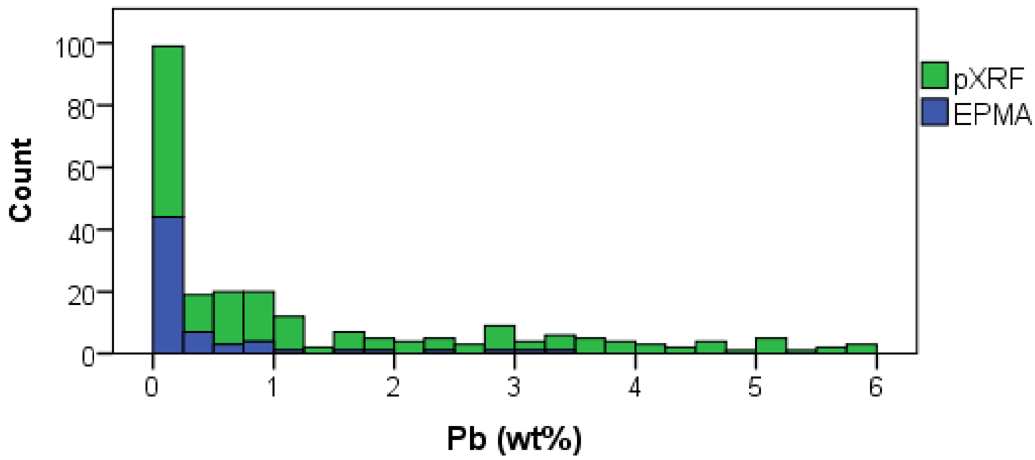


Figure 5.16. Lead distribution of impurity levels for the EPMA and pXRF datasets

Tin impurities have been detected in 19 objects in total, namely 2 detected with EPMA and 17 with pXRF (see also Chapter 4.2.1). The two objects analysed with the EPMA are both examples of relatively pure, unalloyed copper with mean values of 0.02% and 0.03% for tin and lead respectively. In the pXRF dataset, seven samples contained <1% tin with a mean of 0.4% tin and absence of lead. The rest of the pXRF low tin group (<4% Sn) with a mean of 2.7% tin have to be taken as accidentally tinned from mixing and recycling of metal. Of these samples, five objects have presented lead impurities with a mean of 0.5% lead. Fibula M 1843.1 with a zinc content of 9% and minor concentrations of tin and lead is a unique find in the assemblage and has been discussed elsewhere (see Chapter 4). Finally, no further correlations between the tin and the rest of the trace or minor elements analysed were noted.

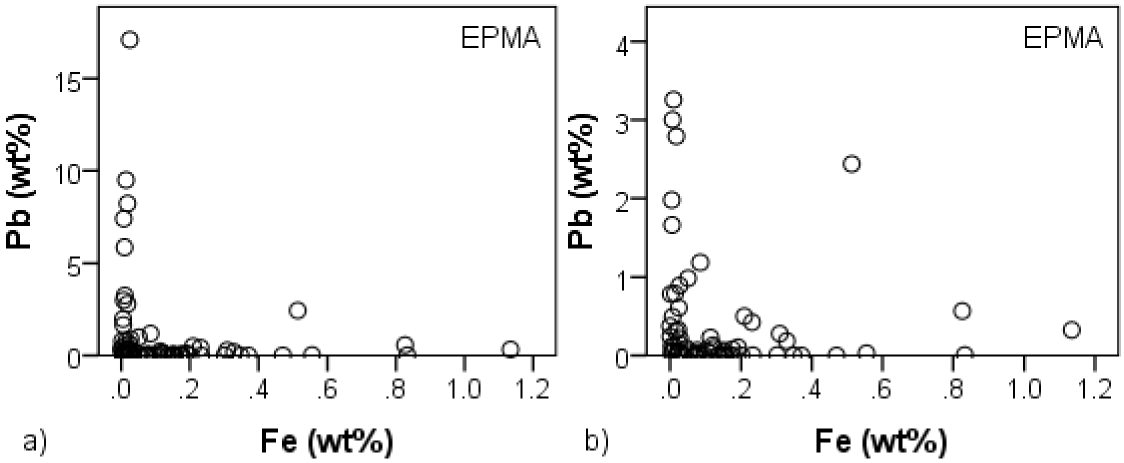


Figure 5.17. Scatterplot of iron against lead for EPMA where objects with either high iron or high lead content are visible (A) in the whole assemblage (n=70) and (B) in <4% Pb artefacts (n=65)

For the lead content, even though the same lead value, i.e. 4% Pb, has been used to distinguish between impurities and intentional additions for both the EPMA and pXRF datasets, it is worth noting that values for lead analysed in the pXRF dataset could be somewhat higher, i.e. 6% Pb, than the actual values based on evidence from the analyses of certified reference material (see Chapter 3.3.1, Figure 3.15). Samples with lead impurities as analysed with both methodologies have produced similar patterns and correlations between the different elements. For example, a pattern where lead-rich objects have low iron contents is evident in both datasets (Figure 5.17), even though this pattern is more pronounced in the EPMA dataset. Finally and as already mentioned, both tin and lead most often co-occur with copper minerals which justifies their presence in the copper-based samples.

5.2.1.6 Nickel, Cobalt, Bismuth, Silver and Selenium

Nickel, silver, bismuth, cobalt and selenium are amongst the copper impurities that are less likely affected from the metallurgical processes involved in the different stages of metal production (see also this Chapter 5.1.1) (Pernicka 1999) or by the addition of tin either in its metallic form or as cassiterite (Radivojević *et al.* 2013, p. 1037). For this reason and since their relative concentrations and ratios to the copper content are likely to be less dependent on metal refining processes as opposed to other elements such as lead and iron, or the volatile arsenic and zinc, these elements have been discussed here together. Nonetheless, it is worth taking into considering that experiments conducted have shown that nickel is amongst the elements to be potentially lost upon crucible refining, whereas bismuth has also been reported to be 'extremely volatile' (Tylecote *et al.* 1977, pp. 323, 329). Finally, both Pernicka (1999) and Tylecote *et al.* (1977) agree on nickel and silver being reliable indicators for the source of ancient copper. Examination of the concentrations of the aforementioned elements and their correlations has been conducted in order to reveal possible existing compositional patterns and trends within the Pheraean bronzes. Finally, of this set of five elements, only nickel has been analysed with both methodologies (EPMA and pXRF), whereas the rest of these elements were analysed only with the EPMA.

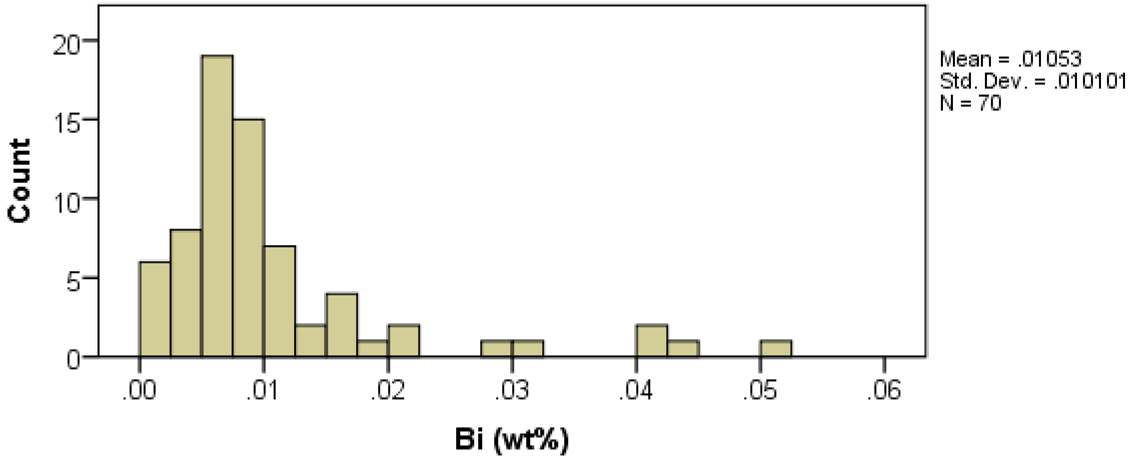


Figure 5.18. Histogram of the bismuth distribution in the EPMA dataset

Z-factor

Significance factor or Z-factor is linked to the probability of a certain hypothesis to be valid or not, i.e. the rejection or not of the null hypothesis. The Z value illustrates how week or intense the association (correlation) between different phenomena is (Aladjev and Haritonov 2004, p. 121). The possible correlation is calculated with the following formula:

$$Y = Y(Z * X)$$

Z-factor can range between -1 and 1. A value close to 1 shows an ideal correlation, whereas a value below 0 suggests that there is too much overlap between the parameters. Z values above 0.5 and 0.0-0.5 indicate an excellent or marginal association between the parameters respectively.

Figure 5.19. The Z-factor

In the EPMA dataset a small group of samples has been distinguished by high values for the aforementioned elements. These high values have been defined primarily on the basis of their respective distribution pattern, as well as on their difference from the mean values for the whole assemblage. For bismuth, for example, the vast majority of samples showed values below 0.02% Bi, whereas six samples show elevated values between 0.03% and 0.05% bismuth (Figure 5.18). These six bismuth-rich samples have been classified as a distinct group worth discussing further. Meanwhile, a similar pattern was evident for the rest of the elements discussed here.

Figure 5.20. Miniature vessel M 798; the ceramic core used during the practice of the lost-wax technique is visible

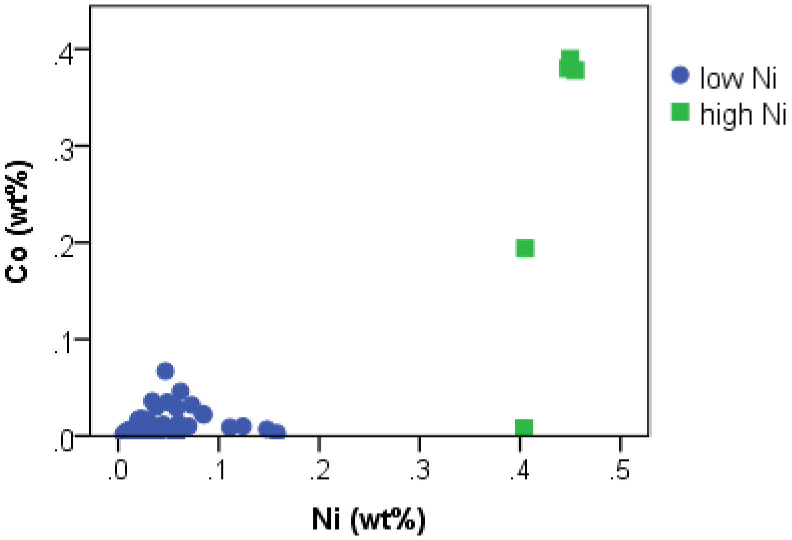


Figure 5.21. Scatterplot of nickel against cobalt for the EPMA dataset where the low and high nickel groups are visible

Between these trace elements, some correlations are visible. Nickel and cobalt values, for instance, are positively related in four out of the five samples in the high nickel group (Table 5.4, Figure 5.21), while this correlation has been further supported by a Z-factor of 0.9 as a result of cluster analysis when the two elements were used to define clusters with (Figure 5.19). It is worth noting that three out of the five samples in the high nickel/cobalt groups are metal sheet fragments which have been catalogued together and it is safe to argue that they belonged to the same object formed of thin metal sheet (M 1217). Nonetheless, taking into consideration the presence of only three objects in the high nickel group and their variable cobalt contents ranging from 0.01% to 0.4% it is difficult to argue for the emergence of a distinct compositional group or pattern. The three nickel-rich objects, i.e. ring AE 34, and sheets M 1217 and AE 744, have to be seen as outliers in the Pheraean assemblage which is characterised by both low nickel and cobalt values. Finally, it is likely that they are the result of different metallurgical practices and/or copper ores used, but the present evidence is not sufficient to support the emergence of a distinct metallurgical tradition within the assemblage (see also discussion below in Chapter 6.3).

Table 5.4. Nickel-rich objects in the EPMA sample (n=5)

Inv.No.		Cu	Sn	Pb	Zn	Fe	Ni	Ag	Sb	As	Co	Se	S	Bi	Mn
AE 34	ring	89.3	4.2	5.86	0.00	0.01	0.40	0.01	0.00	0.03	0.01	0.01	0.01	0.02	0.00
M 1217	sheet	91.1	7.3	0.00	0.00	0.16	0.45	0.00	0.03	0.19	0.39	0.01	0.00	0.01	0.00
M 1217.1	sheet	91.0	7.5	0.00	0.00	0.15	0.45	0.00	0.02	0.22	0.38	0.01	0.02	0.00	0.00
M 1217.3	sheet	90.4	7.7	0.00	0.00	0.17	0.46	0.00	0.03	0.22	0.38	0.01	0.01	0.01	0.00
AE 744	sheet	86.0	12.2	0.79	0.00	0.00	0.41	0.00	0.05	0.22	0.19	0.01	0.02	0.02	0.00

Table 5.5. Selenium-rich objects in the EPMA sample (n=5)

Inv.No.		Cu	Sn	Pb	Zn	Fe	Ni	Ag	Sb	As	Co	Se	S	Bi	Mn
AE 633.1	ring	93.0	6.5	0.05	0.00	0.11	0.01	0.01	0.04	0.10	0.01	0.11	0.01	0.01	0.00
AE 799	ring	89.6	9.8	0.00	0.00	0.07	0.06	0.00	0.03	0.01	0.03	0.10	0.01	0.02	0.00
M 1815.2	fibula	86.6	12.7	0.00	0.00	0.07	0.02	0.00	0.05	0.02	0.00	0.10	0.00	0.01	0.00
AE 549	sheet	92.7	6.3	0.00	0.00	0.47	0.01	0.00	0.00	0.01	0.00	0.09	0.01	0.01	0.00
AE 651	spiral ring	90.2	8.6	0.01	0.00	0.83	0.02	0.00	0.04	0.19	0.00	0.08	0.01	0.01	0.00

Table 5.6. Silver-rich objects in the EPMA sample (n=4)

Inv.No.		Cu	Sn	Pb	Zn	Fe	Ni	Ag	Sb	As	Co	Se	S	Bi	Mn
AE 289	sheet	99.2	0.0	0.24	0.00	0.00	0.02	0.11	0.07	0.07	0.00	0.02	0.00	0.01	0.00
1308	metal band	99.4	0.0	0.38	0.00	0.00	0.02	0.04	0.01	0.07	0.00	0.00	0.01	0.02	0.00
M 798	vessel	70.1	7.0	17.10	0.00	0.03	0.04	0.04	0.09	0.16	0.00	0.01	0.08	0.05	0.00
AE 619	sheet	89.8	9.9	0.02	0.00	0.02	0.02	0.03	0.05	0.01	0.00	0.00	0.01	0.00	0.01

Table 5.7. Bismuth-rich objects in the EPMA sample (n=6)

Inv.No.		Cu	Sn	Pb	Zn	Fe	Ni	Ag	Sb	As	Co	Se	S	Bi	Mn
M 798	vessel	70.1	7.0	17.10	0.00	0.03	0.04	0.04	0.09	0.16	0.00	0.01	0.08	0.05	0.00
AE 507	ring	79.5	10.9	7.40	0.00	0.01	0.04	0.00	0.20	0.05	0.01	0.01	0.09	0.04	0.00
1310	ring	88.6	2.5	8.21	0.00	0.02	0.03	0.01	0.52	0.07	0.00	0.01	0.02	0.04	0.00
AE 796	ring	81.3	13.9	3.26	0.00	0.01	0.07	0.00	0.07	0.03	0.03	0.01	0.07	0.04	0.01
AE 506	ring	79.0	10.8	9.49	0.00	0.01	0.02	0.00	0.07	0.13	0.00	0.02	0.03	0.03	0.00
AE 760.2	ring	87.3	11.6	0.02	0.00	0.03	0.12	0.00	0.09	0.64	0.01	0.02	0.06	0.03	0.00

For the rest of the trace elements detected in higher concentrations than the average in the EPMA dataset such as silver, selenium, and bismuth values have been mostly found independent (Table 5.5-7). Miniature vessel M 798 which consists of a 17% Pb leaded bronze with higher bismuth and selenium values is an exception to the above (Table 5.6, Figure 5.20). Furthermore, analysis of the miniature vessel also produced oxygen and chlorine contents of 2% and 3% respectively suggesting that the analysed area could have been affected by corrosion processes which could have further affected compositional results and the trace elements concentrations. In addition, the presence of relatively high values for bismuth, silver, and selenium in M 798 can also been explained by the high lead content in the alloy since these trace elements are geologically related to lead even though such a pattern is not seen in the rest of the leaded bronzes in the EPMA dataset (Table 5.7). Finally, all five leaded bronze objects analysed with the EPMA are bismuth rich, whereas only one bismuth-rich object (ring AE 760.2) is made of a binary copper-tin alloy (Table 5.7, Figure 5.22).

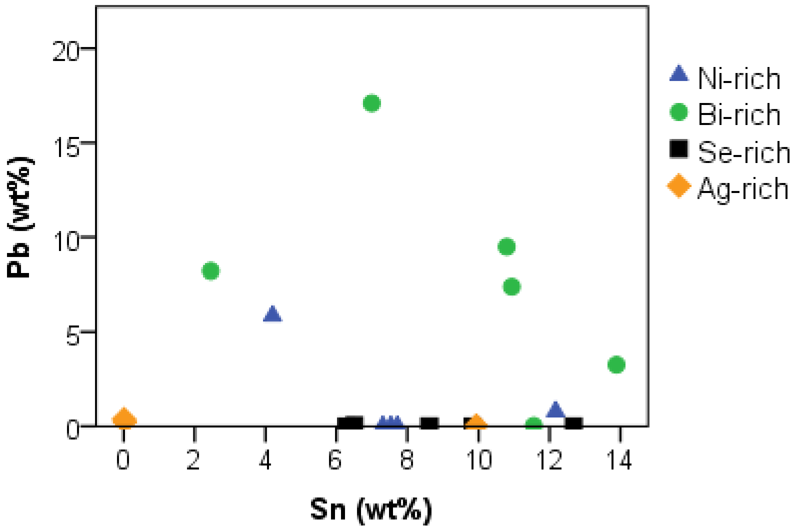


Figure 5.22. Scatterplot of tin against lead for the samples rich in nickel/cobalt, bismuth, selenium and silver (EPMA)

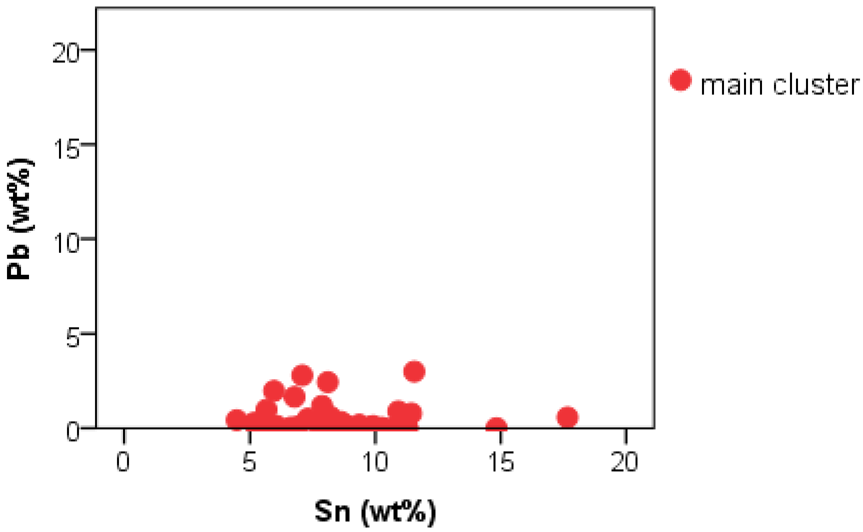


Figure 5.23. Scatterplot of tin against lead for the objects in the EPMA dataset excluding any outliers with concentrations in Ni, Ag, Bi, Co, or Se (n=58) where a cluster is visible for binary tin bronze with moderate additions of tin; two outliers are also visible

5.2.2 Discussion

Overall, trace element concentrations in the bronzes from Pherae fall into characteristic patterns most often seen in ancient copper-based artefacts as indicated by their positive (left-skewed), steep distributions with a rather long tail which was seen in all trace elements analysed with both analytical methodologies. The typically low trace and minor contents as analysed with the EPMA suggest that rather efficient refining techniques took place. Close clustering of the trace element concentrations for the vast majority of the samples, i.e. 83% of the EPMA dataset, points to a relatively limited degree of heterogeneity in the metallurgical operations and raw materials involved in the production of the assemblage. This clustering can be seen in the scatterplot of nickel against cobalt as well where the vast majority of the samples cluster around low nickel and cobalt values (Figure 5.21). Even though a few outliers were found for some of the trace elements (see above this Chapter 5.2.1.6), the vast majority of the samples typically falls under a main cluster which covers 58 out of the 70 samples in the EPMA dataset with mean values for tin and lead of 8.5% and 0.4% respectively. This further suggests the existence of a quite distinct pattern of copper alloying where binary bronze is mainly produced with the addition of moderate amounts of tin (Figure 5.23). Overall, the tight clustering of values indicated by the trace element concentrations, is further supported the major elements' additions too pointing to a copper-based technology for Early Iron Age Pherae and Thessaly with quite distinct characteristics. The possibility of imported artefacts deposited at the Sanctuary of Enodia in the 8th to 6th centuries BC as suggested by outliers in the trace and major elements will be further discussed below where compositional results will be looked at in conjunction with artefact typology (see Chapter 7).

Chapter 6. Alloying practices in ancient Thessaly

As already discussed (see Chapter 4), tin is present in the vast majority of the samples with mean and median values of 9% Sn as analysed with both methodologies (Table 4.2). All the same, both the pXRF and EPMA datasets point to a bimodal distribution for tin which is noted either when they are combined or even plotted individually (Figure 4.3a-c). The latter observation led to a closer examination of the possible alloy recipes emerging in the sample which is discussed below.

All tin-bearing objects in the entire sample with >4% tin or with clear indications of alloying such as ring 1310 with almost 3% tin and 8% lead have been further explored (n=261). Inclusion of both datasets (pXRF and EPMA) allowed for any hypotheses to be tested against a much larger sample since 63 tin-bearing samples have been examined with the EPMA as opposed to 198 with the pXRF. Conversely, exploration of the trace elements was based solely on the EPMA results due to the instrument's superior performance such as its lower detection limit, and better accuracy and precision levels (see above Chapters 3 and 4).

Starting point for the interpretation of the bimodal distribution for the tin content was the examination of the different alloy recipes such as tin bronze and leaded bronze individually as separate compositional groups. Publications of copper-based alloys often deal with the tin content regardless of possible additional elements present, e.g. lead. Such an approach was, for instance, adopted by Craddock (1976, 1977, 1978) who grouped together the different artefact types such as the mirrors, vessels, and tools, but did not explore further the alloy recipes on their own right. Hence, bronze and leaded bronze alloys have been hereby discussed before artefact typology in order to reveal any possible patterns in the modes of addition of tin and lead (for a discussion of artefact typology in conjunction with alloy recipes see Chapter 7). Finally, the possibility for two workshops operating in Thessaly within the time span covered by the Pheraean assemblage has been considered.

6.1 Alloy recipes

In order to examine the nature of tin additions by avoiding the diluting effect that would occur in ternary leaded bronze, the lead content has been subtracted, and totals have been recalculated and renormalised to 100%. This would provide tin values independent of the lead ones since variable lead additions in the same batch of tin bronze would have affected tin percentages (wt%), namely the more lead added the less the tin amount would be detected during quantitative analysis. The above is based on the hypothesis that purposefully added lead (>4% Pb) was added as a distinct ingredient either as a final alloying step after tin bronze was produced or simultaneously with the tin in a single alloying operation. On the contrary, lead additions of <4% might as well have resulted from the coincidental use of lead-bearing copper ores and have therefore not been considered here.

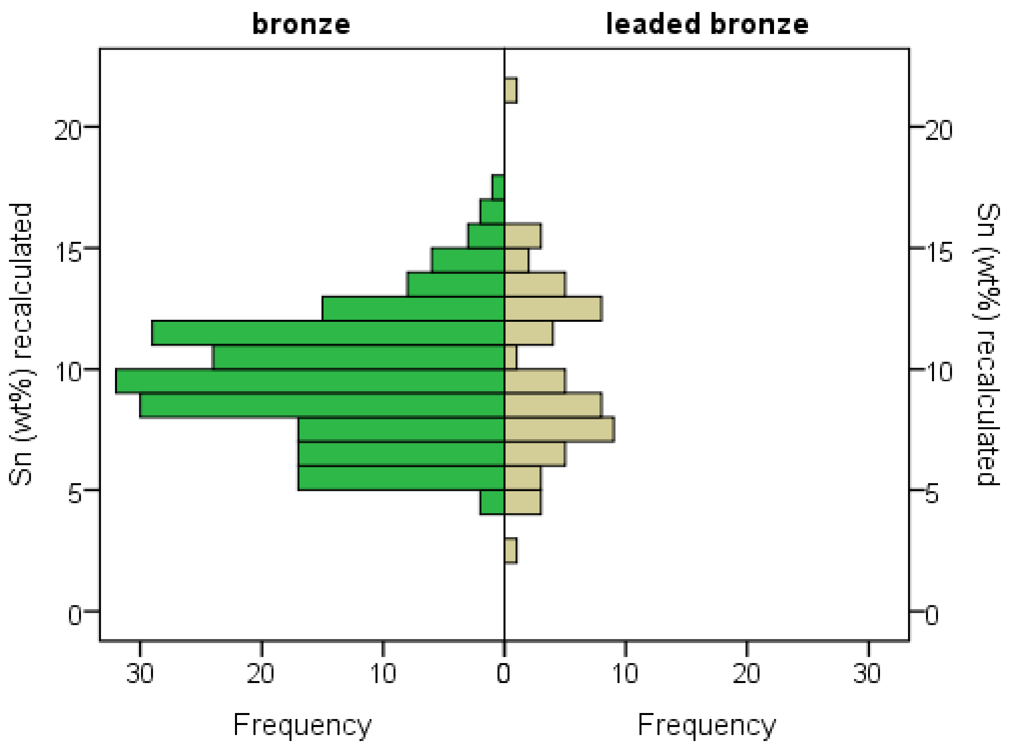


Figure 6.1. Comparison of the tin distribution in the bronze and leaded bronze groups in the assemblage (EPMA & pXRF); tin has been recalculated after the lead content has been removed in order to investigate the relationship of lead addition in binary tin bronze

6.1.1 Tin additions

Plotting the recalculated/renormalised values for tin in histograms according to alloy type, namely tin bronze and leaded bronze, a distinct pattern emerged (Figure 6.1). Tin content for binary bronze showed a normal, single-curve distribution, whereas a bimodal, two-peak distribution was noted for leaded bronze. Even though a drop in objects with 10% tin was also noted for tin bronze, this was not as pronounced as for leaded bronze. Furthermore, mean and median tin values for the binary bronzes of 10% are comparable to the ones for the entire sample of tin-bearing objects, while the decrease in the frequency of the objects with 10% tin could be interpreted as trace of a bimodal distribution (Table 6.1). Meanwhile, this clustering of the tin contents below and above a content of 10% Sn is further supported when looking at the EPMA and pXRF analyses separately (Figure 6.4 & 5). Conversely, in the leaded bronze group (n= 58), where the presence of two modes for tin is much more marked, the two peaks correspond to mean and median values of 7% and 13% tin respectively (Table 6.1, Figure 6.2) and modes of 7% and 12% further support the presence of two normal distribution curves (note: a normal distribution is defined by equal values for all averages, i.e. mean, median and mode). For the purposes of the present discussion, these tin groups have been classified as low and medium tin groups respectively. Finally, standard deviation values of 1-2% for the additions of tin point to a rather limited dispersion of values which is also visible in the histograms (Figure 6.2 & 4, Table 6.1), thus suggesting that the addition of tin to copper was closely controlled.

Table 6.1. Summary of tin (recalculated after lead content was subtracted from the totals) and lead for the leaded and binary bronze as seen in both datasets (EPMA & pXRF); distinct values for the low and medium tin groups for the leaded bronze are visible

	leaded bronze (n=58)				**bronze (n=203)**		**total alloyed (n=261)**	
	low tin (n=34)		**medium tin (n=24)**					
	Sn	Pb	Sn	Pb	Sn	Pb	Sn	Pb
Mean	**7.28**	8.59	**13.34**	9.52	9.70	0.95	9.72	2.73
Median	7.64	6.81	12.74	7.23	9.87	0.50	9.74	0.86
Min	2.68	4.02	10.86	4.05	4.51	0.00	2.68	0.00
Max	9.86	26.54	21.80	22.33	18.00	3.99	21.80	26.54
Std. Dev.	1.68	5.21	2.26	5.52	2.60	1.14	2.84	4.29

6.1.2 Lead additions

Despite the above evidence for the controlled addition of tin in copper, the same is not evident for the lead content. Results point to variable lead amounts being added regardless of the tin content which spread randomly across the low and medium tin groups (Figure 6.3). No correlation between the tin and lead contents was found, i.e. low, medium or high tin concentrations in the copper do not seem to have affected choices in the lead additions since both tin groups showed similar lead contents ranging from 4% to >20% Pb (Figure 6.3). Furthermore, both tin groups showed a mean lead content of approximately 9%, and comparable median, minimum and maximum values. Variation in the lead additions is further reflected in the standard deviation values of purposefully added lead (>4% Pb) of 5% (Table 6.1). Nonetheless, a preference for lead contents of up to 8% Pb is visible and covers 62% of the leaded bronze group (36 out of 58 objects with both low and medium tin contents). Finally, lead was rarely found to tin bronze with > 15% tin, whereas there is only a single object (bead AE 451) which is both leaded and tin-rich with 5% lead and 22% tin (see also Chapter 7).

The presence of these low and medium tin groups (unalloyed and zinc-rich objects excluded) has been further illustrated by cluster analysis when tin and copper was selected to create segments which were confirmed by a Z-factor close to 1. This pattern was seen both before and after renormalisation of the copper and tin values.

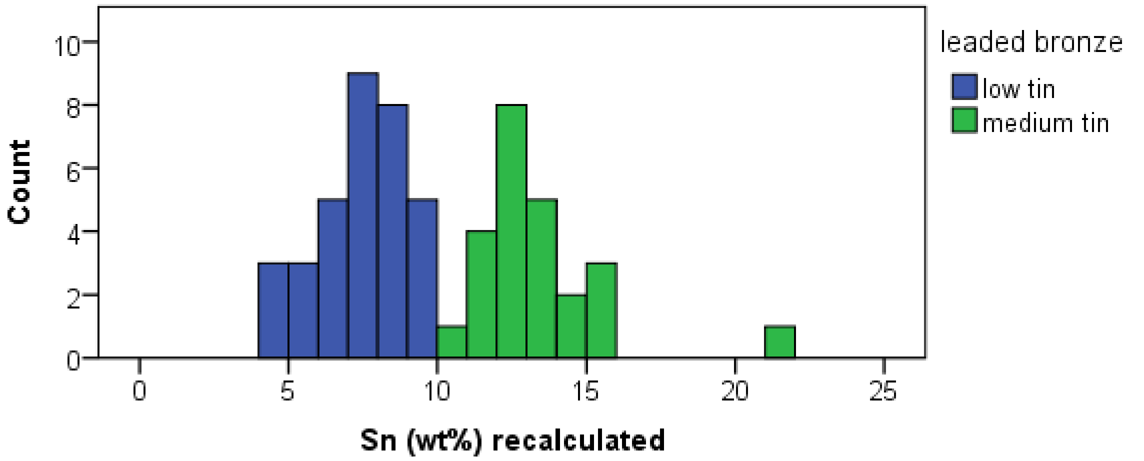


Figure 6.2. Histogram of the tin content recalculated in the leaded bronze objects (n=57) in both datasets (EPMA & pXRF) where a bimodal distribution is visible

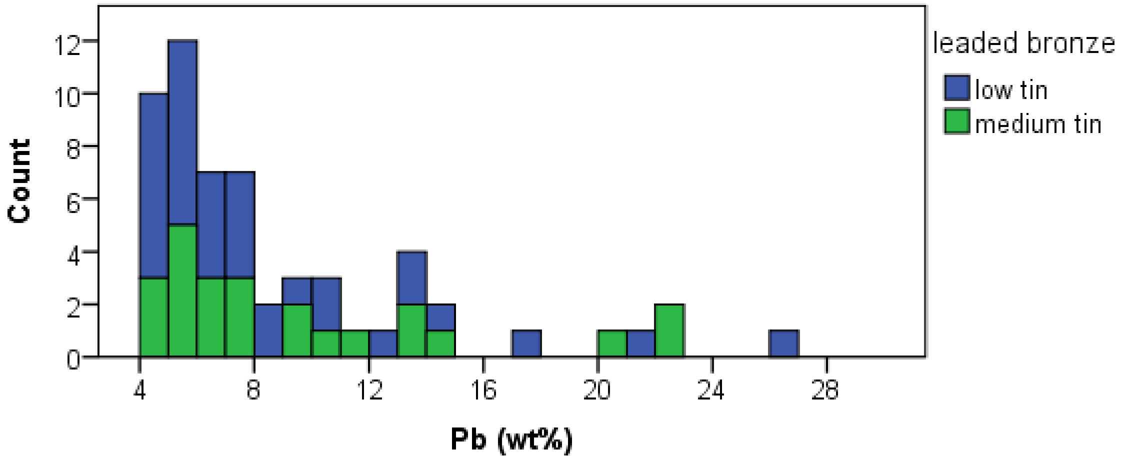


Figure 6.3. Histogram of the lead content in the leaded bronze objects according to the tin content (low and medium) (EPMA & pXRF)

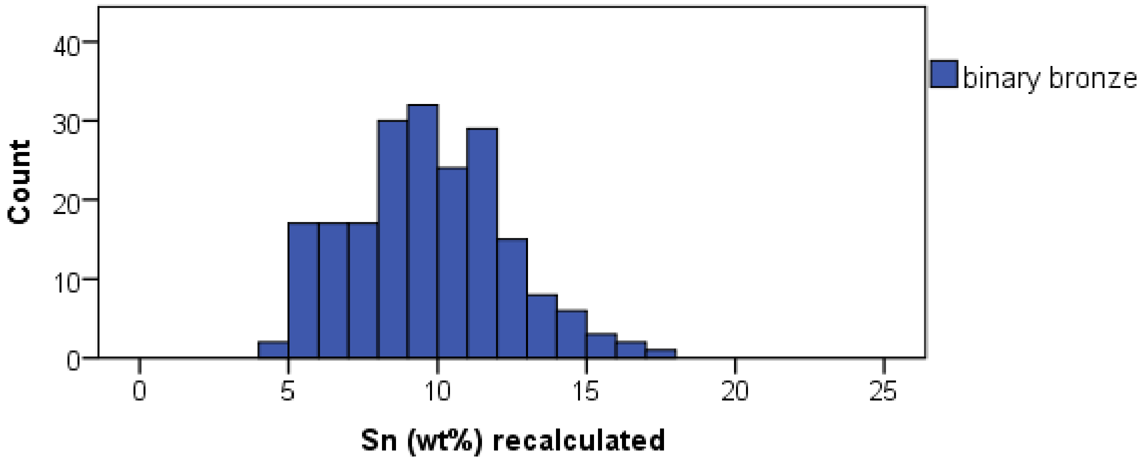


Figure 6.4. Histogram of tin distribution (recalculated) in the binary bronze group (EPMA & pXRF)

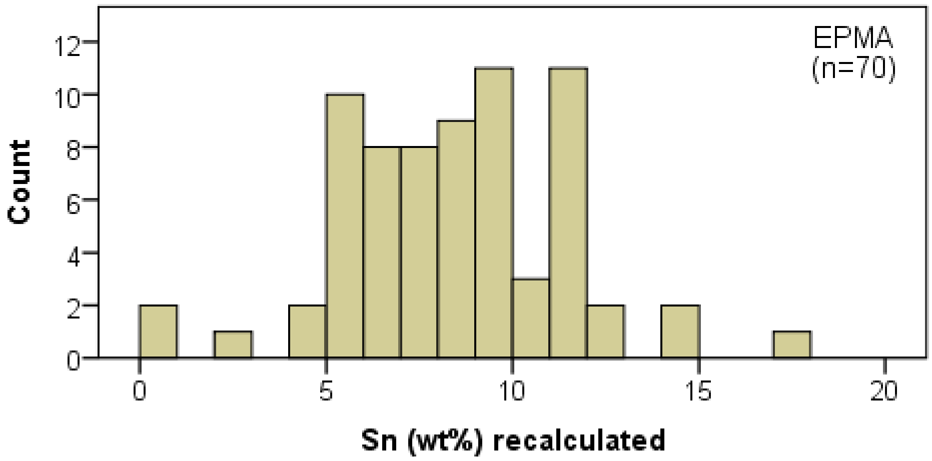


Figure 6.5. Histogram of tin (recalculated after lead was subtracted from the totals) distribution in the EPMA dataset; a division between values below and above 10% Sn is visible (63 bronze, 5 leaded bronze objects)

Overall, the above pattern points to a general preference for a medium tin bronze with an average of 10% tin and lead impurities, while more particular choices seem to have taken place when lead was purposefully added in which case two quite distinct alloy recipes seem to be usually preferred. The control exercised over the addition of tin for both alloy recipes, was not noted for lead which was added rather arbitrarily with a general preference for contents up to 8% lead. The above observations pose further questions in regard to the alloying techniques practiced, access to tin and lead metals and possible diachronic changes for the copper workshop(s) of Thessaly and Pherae.

6.2 Trace element fingerprints for alloy recipes

Questions put forward with regard to the possibility for two different alloying traditions as reflected in the tin distribution are further explored through the trace element fingerprints as analysed with the EPMA. Starting point for the examination of the trace elements' concentrations was the hypothesis that different technological traditions could have left a characteristic imprint on the trace/minor element concentrations in the produced objects as a result of different raw materials used in conjunction with specific metalworking techniques employed during the different stages of metal object production (see also Chapter 5). Due to the leaded bronze group in the EPMA dataset being too small for any definite conclusions to be drawn (5 objects), trace elements of only binary copper-tin alloys objects (>4% Sn, <4% Pb) have been examined (63 objects). Leaded samples have been excluded since certain trace elements that are often associated with lead such as bismuth or silver would potentially affect results in the form of outliers (see also below Figure 6.21 and Chapter 6.4). Finally, discussion below took into consideration the detection limit of the EPMA at approximately 100 ppm and it is argued that further investigation with more sensitive analytical techniques would be needed for a more detailed exploration of this hypothesis.

Table 6.2. Summary table of the trace element concentrations in binary bronze as analysed with EPMA

bronze (EPMA, n=63)												
	Sn	**Pb**	**Se**	**Ag**	**As**	**Fe**	**S**	**Bi**	**Co**	**Sb**	**Ni**	**Mn**
Low tin	7.56	0.34	0.022	0.004	0.16	0.184	0.030	0.007	0.035	0.069	0.065	0.003
Med. tin	12.07	0.59	0.022	0.002	0.14	0.095	0.032	0.012	0.019	0.074	0.066	0.003
δ abs	-4.51	-0.25	0.00	0.002	0.01	0.09	0.002	0.00	0.02	-0.01	0.00	0.00
δ rel	-60	-74	0	50	13	48	-7	-71	46	-7	-2	0
	Sn	***Pb**	***Se**	***Ag**	***As**	***Fe**	***S**	***Bi**	***Co**	***Sb**	***Ni**	***Mn**
Low tin	7.56	0.37	0.024	0.004	0.17	0.198	0.033	0.008	0.038	0.074	0.07	0.003
Med. tin	12.07	0.68	0.025	0.002	0.16	0.111	0.037	0.013	0.022	0.084	0.075	0.003
δ abs	-4.51	-0.31	-0.001	0.002	0.01	0.087	-0.004	-0.005	0.016	-0.01	-0.005	0.000
δ rel	-60	-84	-4	50	6	44	-12	-63	42	-14	-7	0

*recalculated values for the trace elements after tin was subtracted from the totals

Looking at the trace element concentrations in the low and medium tin groups even though certain elements appear to have similar or even identical mean and median values, other elements including silver, cobalt, iron, bismuth and lead (<4% Pb) present a relative difference of 50-70% for the two tin groups (Figure 6.6). These values have been further confirmed when trace element values were recalculated and renormalised after the tin content was subtracted from the totals. At this point, it is worth mentioning that some of the particularly low values for the trace elements could be the result of the background noise produced by the analytical instrument itself. However, a closer look at the emerging pattern would still have some value since all the data examined here have been produced by the same instrument and, thus, the same set of limitations apply to all values.

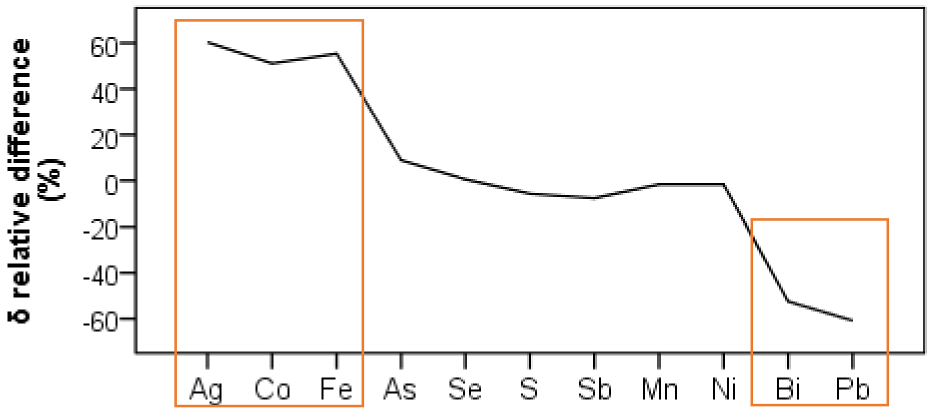


Figure 6.6. Line graph of the δ relative difference for the trace elements in the bronze group (EPMA, n=63); δ relative values for the medium tin group have been subtracted from the low tin group values; lead values only <4% are considered

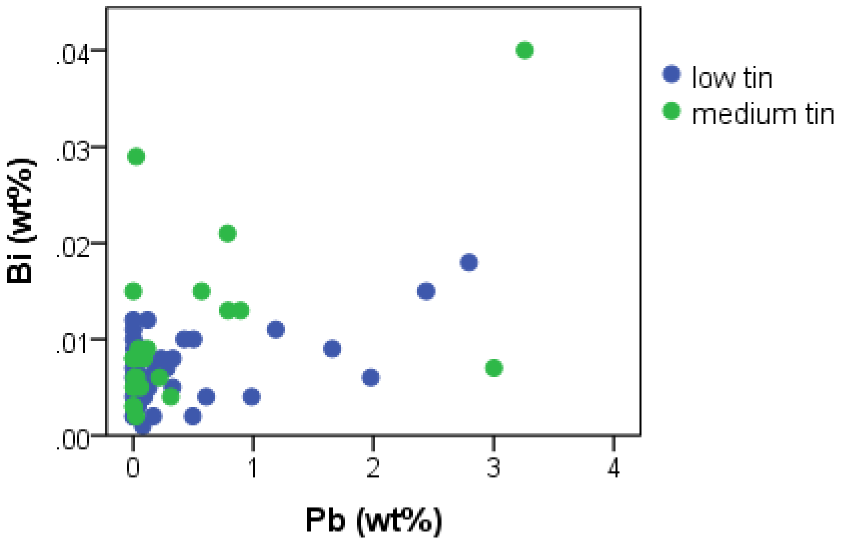


Figure 6.7. Scatterplot of lead (<4%) against bismuth for the low and medium tin groups (EPMA, n=63)

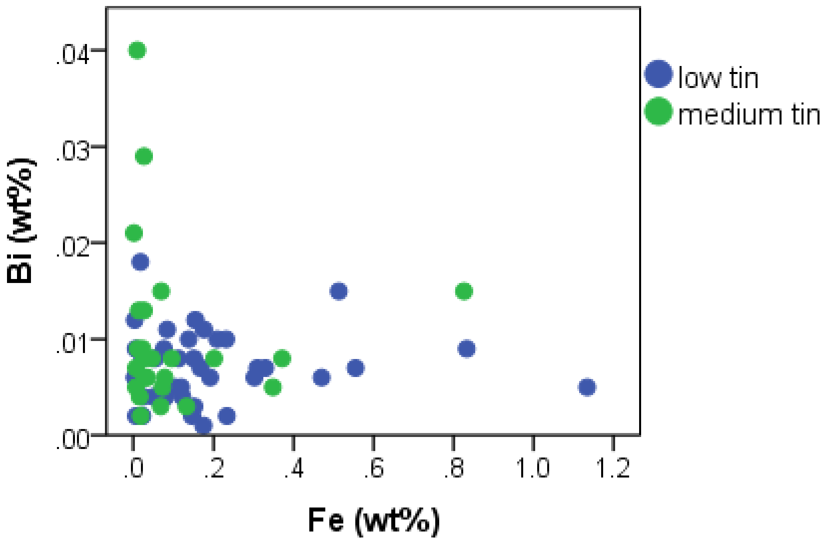


Figure 6.8. Scatterplot of iron against bismuth for the low and medium tin groups in the EPMA dataset; iron-rich samples typically belong to the low tin group

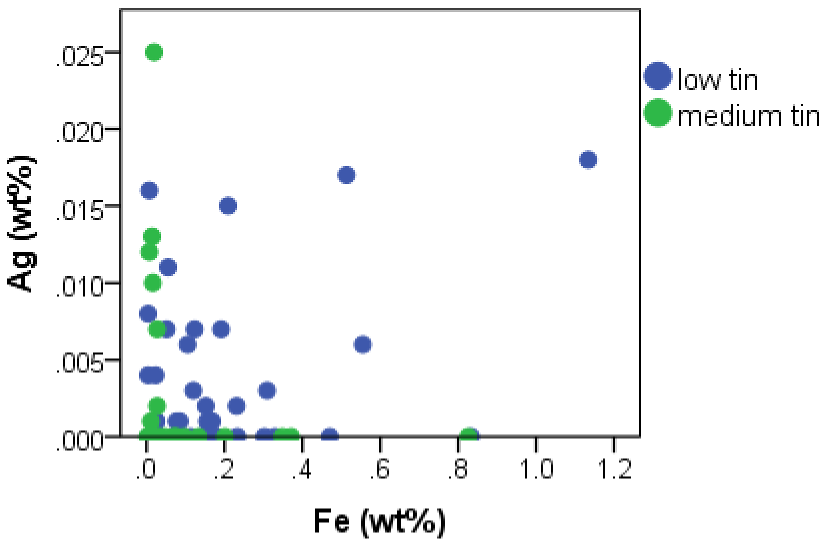


Figure 6.9. Scatterplot of iron against silver in the EPMA dataset according to the tin content (n=63)

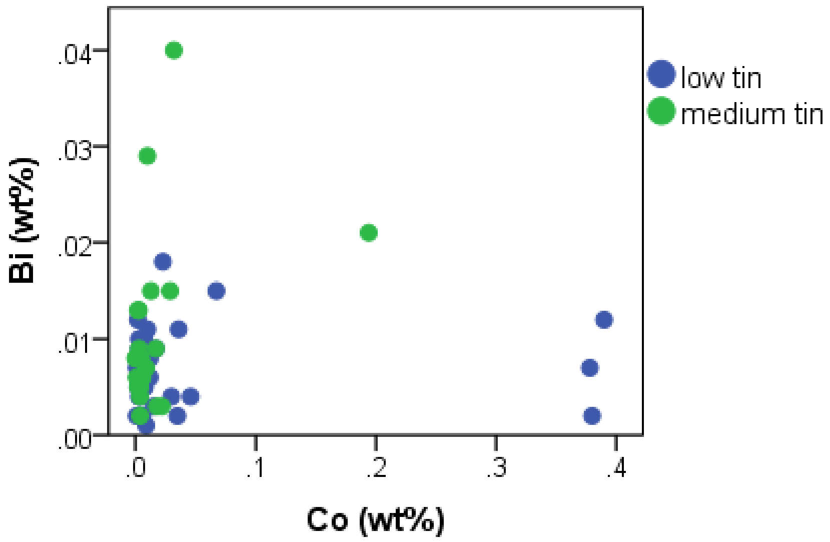


Figure 6.10. Scatterplot of cobalt against bismuth for the low and medium tin groups where cobalt- and bismuth-rich outliers are visible in the low and medium tin groups respectively (EPMA, n=63)

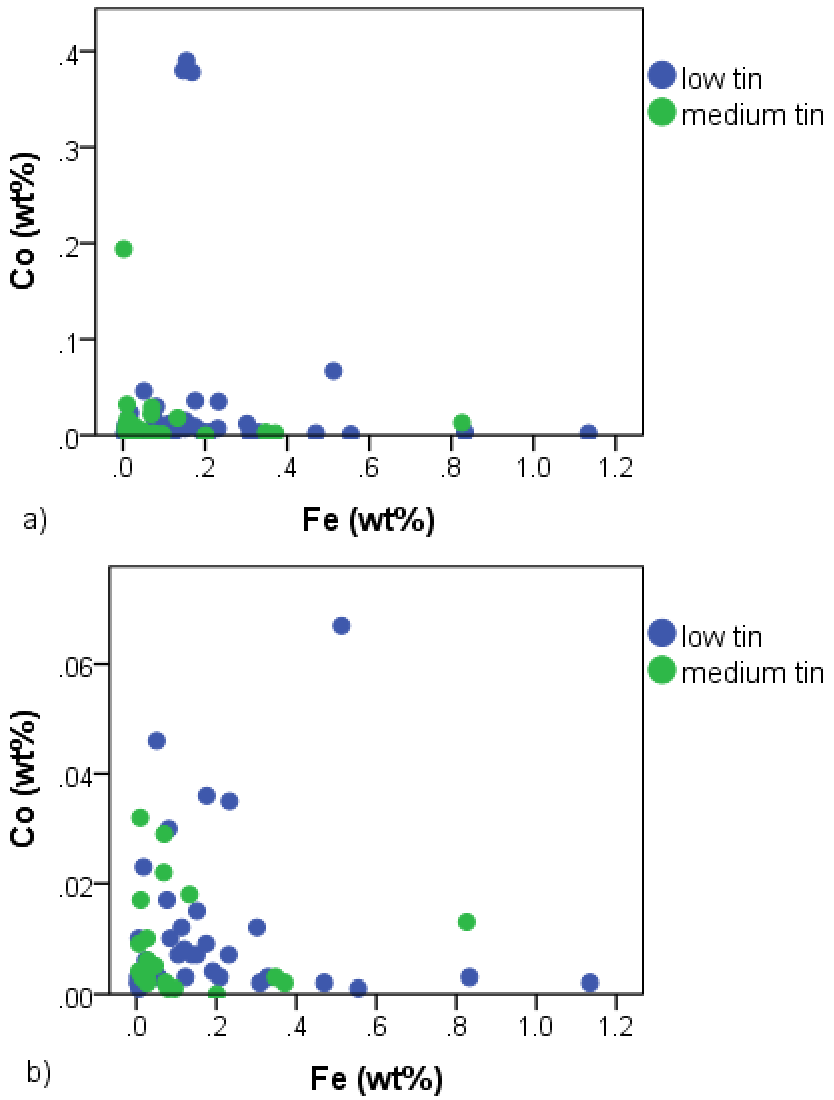


Figure 6.11. Scatterplots of iron against cobalt for the low and medium tin groups in (A) all binary copper-tin samples (EPMA, n=63) and (B) without cobalt outliers (n=59)

Overall, quantitative data showed some evidence to support the presence of two patterns for the addition of tin in copper as particularly seen in the bimodal distribution of the tin content in the leaded bronze group which was confirmed in the results of both analytical techniques (pXRF and EPMA). Furthermore, renormalised values for the trace elements in the copper alloys possibly point to the emergence of different patterns for the trace element fingerprint of the low and medium tin groups in both the binary and leaded bronze groups (Table 6.2). Larger relative differences seen in the cobalt, antimony and iron values could be taken as indications for the use of different copper ores for the production of the Pheraean assemblage. Nonetheless, at the present state of research it is not possible to come to definite conclusions on the above observations. Finally, it is argued that future analyses with detection limits at the ppm level could shed more light on any patterns amongst the trace element concentrations.

Particularities between the alloy recipes and alloying traditions with artefact typology is further discussed in the following chapter.

6.3 Evidence for *in situ* alloying at Pherae

In addition to the thousands of copper-based objects from the Pheraean sanctuary, traces of a bronze working workshop dating to the Archaic period have been recovered from the settlement as well including a couple of tuyère and crucible fragments (Doulgeri-Intzesiloglou 1994). On the crucible, traces of firing and corroded copper remains are visible macroscopically (Figure 6.12). Below, EPMA analysis of the sample cut from the inner part of the crucible is discussed in conjunction with the objects' EPMA results. The crucible sample was examined microscopically under reflected light, while several area and spot analyses have been conducted with the EPMA.

Figure 6.12. Crucible fragment from the settlement of Pherae (after Doulgeri-Intzesiloglou 1994)

6.3.1 Metallography

Microscopically the crucible fragment AE 215 revealed a large metal prill with an overall good preservation state as a substantial area of sound metal is visible (Figure 6.13). Only towards the surface of the metal some inter-granular corrosion which has highlighted the metallic grains was found, while the metal prill is surrounded by layers of corrosion products and slag remnants. Towards the centre of the large metal prill a granular structure is visible in which copper-rich metallic grains are highlighted by tin-rich outlines (coring) as a result of a rather slow cooling rate (Figure 6.14). Such a cooling rate causing this layering in the bronze grains could have easily occurred as a result of emptying the crucible charge and leaving the ceramic vessel to slowly cool down before it was reused. Large gas-holes are also visible towards the centre of the metal prill, while smaller ones occur nearer to the surface. Additionally, minute tin-rich prills as recognised from their bright whitish colour usually with a diameter of just a couple of microns were found trapped in the slag matrix (Figure 6.15 & 6.16). One of these tin-rich prills has preserved a characteristic eutectoid structure comprising of a copper- and a tin-rich phases, from which only the tin-rich phase has survived, while the copper-rich metal has been corroded (Figure 6.15b). This pattern is often seen in ancient bronzes and would have been also favoured by the corrosion-resistant properties of tin metal (e.g. Orfanou 2009). Finally, few sulphide inclusions have been also found in the bronze from the crucible fragment pointing to the sulphidic nature of the copper ore used during these alloying operations.

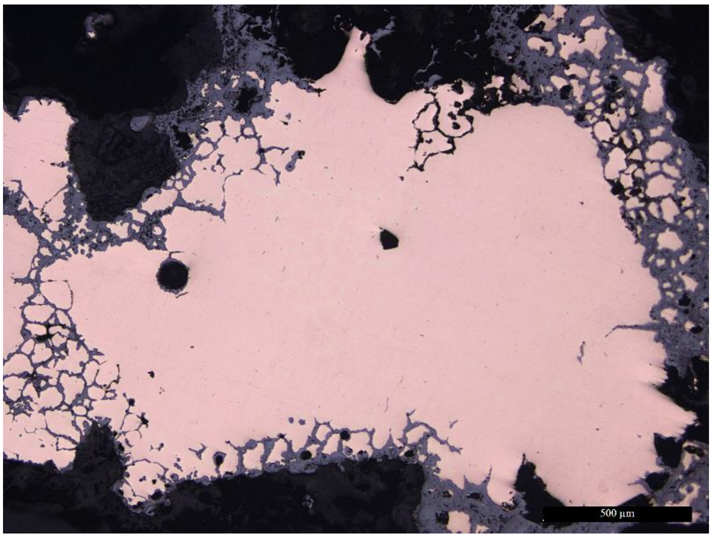


Figure 6.13. Photomicrograph of crucible fragment AE 215 where an overview of the large metal prill surrounded by a matrix of slag and corrosion products is visible; OM, PPL, 50x

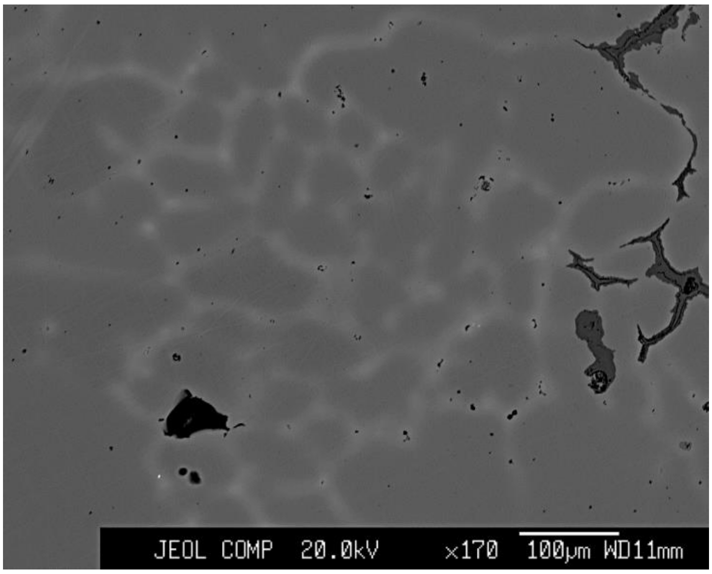
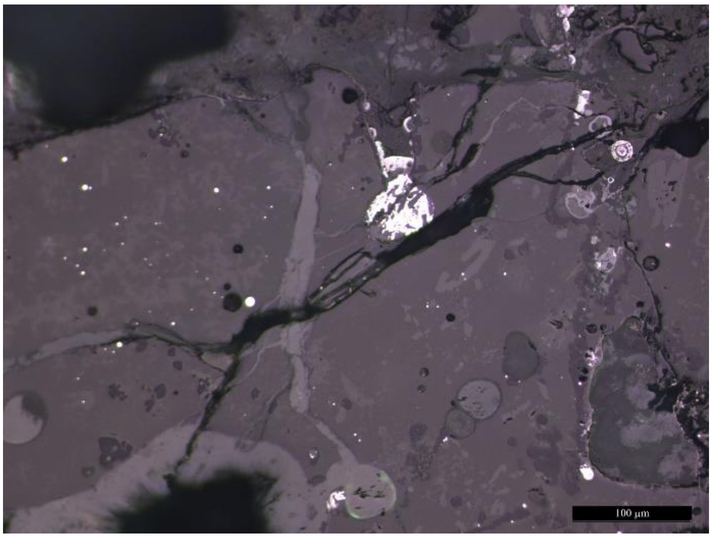


Figure 6.14. BSE image of crucible fragment AE 215 (area A3) where copper-tin grains (grey) highlighted by tin-rich borders (light grey) are visible; EPMA, 170x

a) 

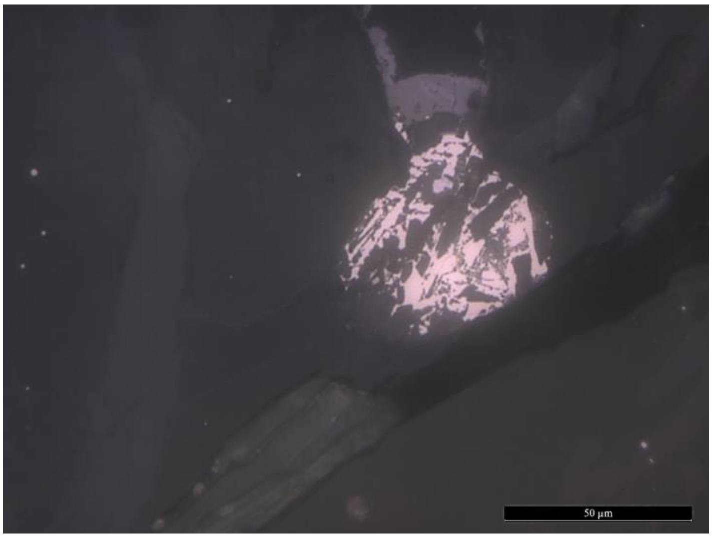
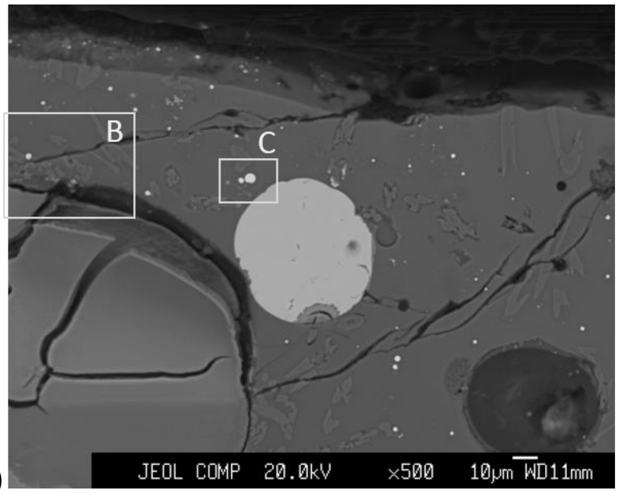
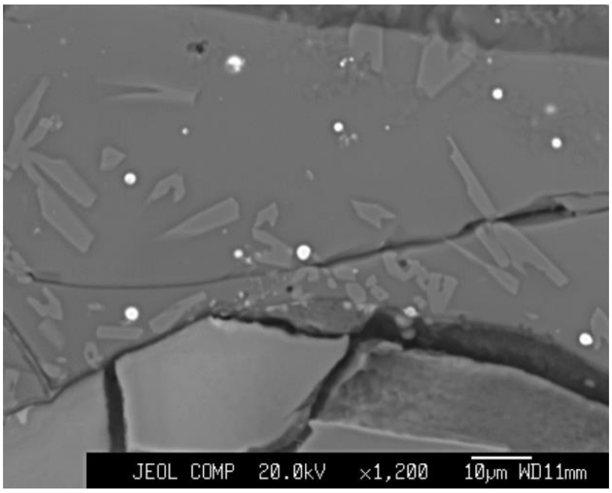
b) 

Figure 6.15. Photomicrograph of crucible fragment AE 215 where (A) tin-rich prills (white) are trapped in a slag matrix (grey) and (B) a large tin-rich bronze prill with a eutectoid structure from which the copper-rich phase has corroded, while the tin-rich phase (white) has survived; OM, PPL, (A) 500x, (B) 1000x

a) 

b) 

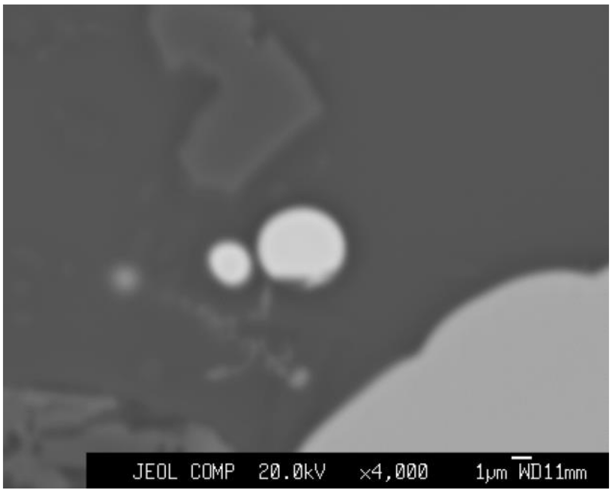
c) 

Figure 6.16. SE images (spot B1 & B2) showing minute tin-rich prill in the slag matrix, (B) and (C) are magnifications of (A); EPMA, (A) 500x, (B) 1200x, (C) 4000x

6.3.2 Crucible metal

Quantitative analyses of the crucible was conducted with the EPMA under the exact same conditions and was monitored by the same CRMs as for the objects (see Chapter 3.2.3). Three area and five spot analyses have taken place at different magnifications ranging from 170x to 4000x in order to account for any particular compositions of the different structures present in the metal as described above (Table 6.3). Analyses confirmed the copper-based character of the metal, as well as the tin-rich content of the metallic prills in the slag matrix.

Composition of the copper-based metal which occupies most of the sample's cross-section as investigated with three area and two spot analyses (area A1-3, spot A1 & 2) showed variable tin contents of up to 8.6% tin and absence of lead which was only found at impurity levels, namely <0.1% levels. The trace element fingerprint of these analyses, even though it is not identical, it is comparable to that of the objects' analyses as seen in the overall low values for the different trace elements. Hence, mean and median values for the analyses of the objects and the crucible metal are not exceptionally different as seen in Figure 6.24 (a & b) with the exception of larger values for lead in the analysed objects. In addition, scatterplots for the different trace elements showed that values for the crucible metal typically fall well within the scatter of the values for the objects. Meanwhile, nickel forms the single exception to the above as its values in the crucible metal are consistently larger than in the objects (Figure 6.20). Finally, past analysis has further confirmed that the relationship between the metal residue from crucible and the final produced is not straightforward. Crucible analyses should be largely taken as indicative of the nature of the metals/alloys worked rather than as direct evidence for the element rations as seen in the metal produced (Dungworth 2000).

Table 6.3. Table showing the different spot and area analyses of crucible fragment AE 215

areas of analyses	Cu	Sn	Pb	Se	Ag	As	Fe	S	Bi	Co	Sb	Ni	Mn	Zn
area A1	98.68	0.86	0.01	0.00	0.04	0.04	0.05	0.01	0.00	0.05	0.00	0.17	0.00	0.00
area A2	98.29	1.25	0.00	0.00	0.04	0.03	0.05	0.01	0.01	0.05	0.00	0.16	0.00	0.00
area A3	94.84	4.47	0.01	0.00	0.12	0.15	0.02	0.00	0.00	0.04	0.05	0.18	0.00	0.00
spot A1	90.36	8.65	0.02	0.00	0.21	0.26	0.02	0.00	0.00	0.03	0.10	0.16	0.00	0.00
spot A2	99.33	0.29	0.00	0.00	0.04	0.03	0.02	0.01	0.00	0.05	0.00	0.21	0.00	0.00
spot B1	73.93	22.90	0.04	0.06	0.00	0.08	1.34	0.00	0.00	0.26	0.04	0.43	0.32	0.00
spot B2	78.25	16.59	0.00	0.01	0.01	0.04	1.89	0.01	0.00	0.24	0.03	0.42	0.42	0.00
mean	90.53	7.86	0.01	0.01	0.06	0.09	0.48	0.01	0.00	0.10	0.03	0.25	0.11	0.00
min	73.93	0.29	0.00	0.00	0.00	0.03	0.02	0.00	0.00	0.03	0.00	0.16	0.00	0.00
max	99.33	22.90	0.04	0.06	0.21	0.26	1.89	0.01	0.01	0.26	0.10	0.43	0.42	0.00
S inclusion														
spot A3	78.77	0.25	0.28	0.64	0.02	0.02	0.40	19.14	0.00	0.01	0.00	0.01	0.02	0.01

6.3.3 Tin-rich prills

Contrary to the composition of the crucible metal and the similarities to the overall composition of the objects, analyses of the tin-rich prills showed substantially different compositions. Tin values varied between 17% and 23% tin which were though expected in regard to the nature of the crucible fragment and its metallographic characterisation, namely because the crucible fragment represents a stage of the alloying where tin has not been yet fully incorporated to the copper. In addition, notable variation was found at the trace element concentrations which differ substantially from both the objects and the crucible metal discussed above. Analyses of the tin-rich prills also showed high values for iron, nickel, cobalt and manganese which are often several times larger than the ones seen in the objects' and crucible metal's analyses (Finally, past analysis has further confirmed that the relationship between the metal residue from crucible and the final produced is not straightforward. Crucible analyses should be largely taken as indicative of the nature of the metals/alloys worked rather than as direct evidence for the element rations as seen in the metal produced (Dungworth 2000).

Table 6.3, Figure 6.24c).

The tin-rich prills found in the slag matrix should be taken as representations of an intermediate stage of the process of mixing copper with tin. Their compositions are taken as reflections of the state of the metal before the tin was fully diluted in copper to form the bronze with the desired tin amount which must have been lower than 10% Sn as suggested by the composition of the metal in the fragment. Thus, higher values for certain elements in comparison with proper metal areas in the crucible or the objects as discussed above should be linked to this early stage of the alloying process. It could also be argued that these higher nickel, iron, cobalt, and manganese values would have been lost if further remelting or metalworking of the copper-alloy took place as has been observed with relevant experimental replications of copper refining (Tylecote *et al.* 1977) (see also Chapter 5).

Table 6.4. Summary table of the mean values for the objects, and the metal and tin-rich prills in the crucible fragment; notable differences between the values for the crucible, the tin-rich prills and the objects are highlighted with light grey

MEAN	Se	Zn	Ag	As	Mn	Pb (<4%)	Sb	Ni	Co	Bi	S	Fe
objects	.021	.000	.006	.145	.003	.405	.077	.067	.028	.011	.031	.072
crucible metal	.000	.000	.090	.102	.003	.006	.030	.176	.045	.004	.006	.029
Sn-rich prills	.031	.000	.003	.056	.369	.022	.039	.427	.249	.000	.004	.615

6.3.4 Sulphide inclusions

Analyses of the sulphide inclusions (spot A3) found within the crucible metal showed a 19% sulphur content with traces of selenium (0.6% Se) and iron (0.4% Fe) which have been both expected as both these elements are often associated with sulphur in copper (Table 6.3). In addition, analyses of the sulphide inclusion has so far been the first to provided traces of zinc with 0.1% Zn as measured by the EPMA. Even though, this value is close to the detection limit of the analytical instrument, it is hereby taken to suggest the presence of zinc impurities in the copper which would have been enriched by corrosion products in the surface and substrate of the finished objects and which have been detected by the pXRF.

6.4 Crucible metal and finished objects

Turning to the overall comparison of the objects' and the crucible's composition certain patterns emerged. To start with, the correlation between the lead and the bismuth contents in conjunction with the low bismuth values for the lead-free metal found in the crucible further support the presence of larger bismuth values as introduced from the lead metal (Figure 6.21). Additionally, the nickel and cobalt values as analysed in the crucible metal and the tin-rich prills seem to complement the pattern already seen for the objects examined with the EPMA. Looking at the scatterplot for nickel against cobalt, the vast majority of the objects fall in the low end of the values' spread, while a smaller group of objects along with the compositional evidence from the crucible point to a positive correlation between the two elements (Figure 6.20).

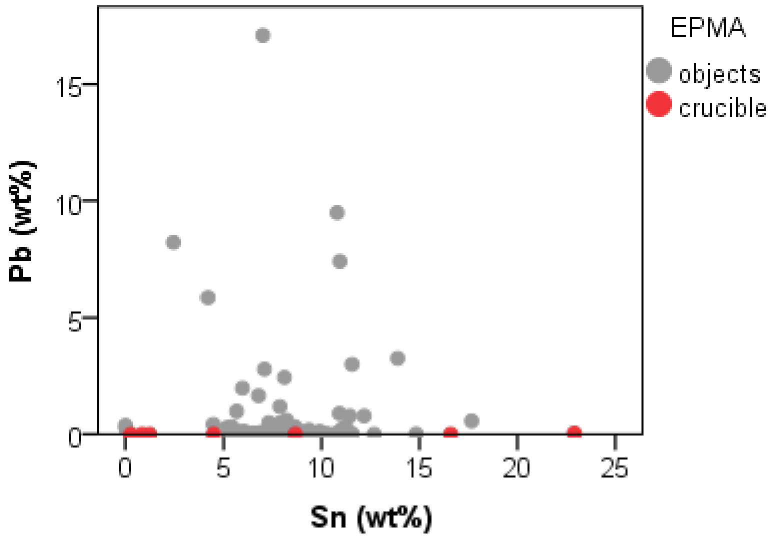


Figure 6.17. Scatterplot of tin against lead where the EPMA results of the objects and the different areas of the crucible are visible

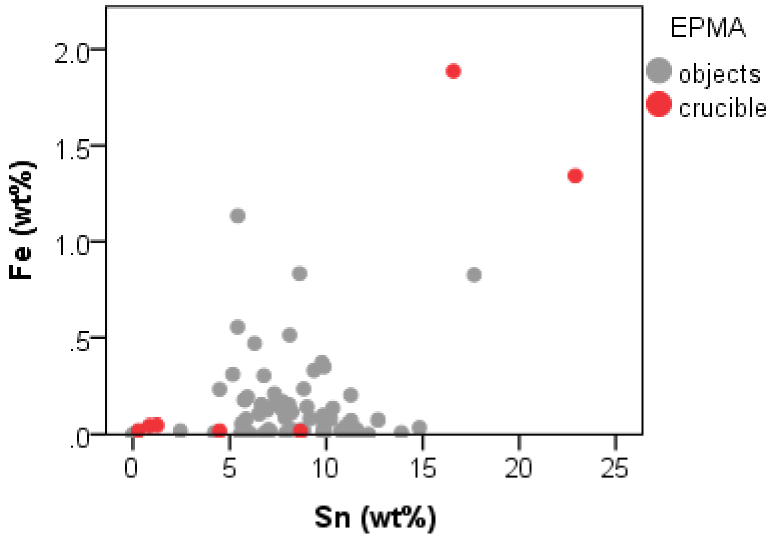


Figure 6.18. Scatterplot of tin against iron for the objects and crucible fragment analysed with the EPMA

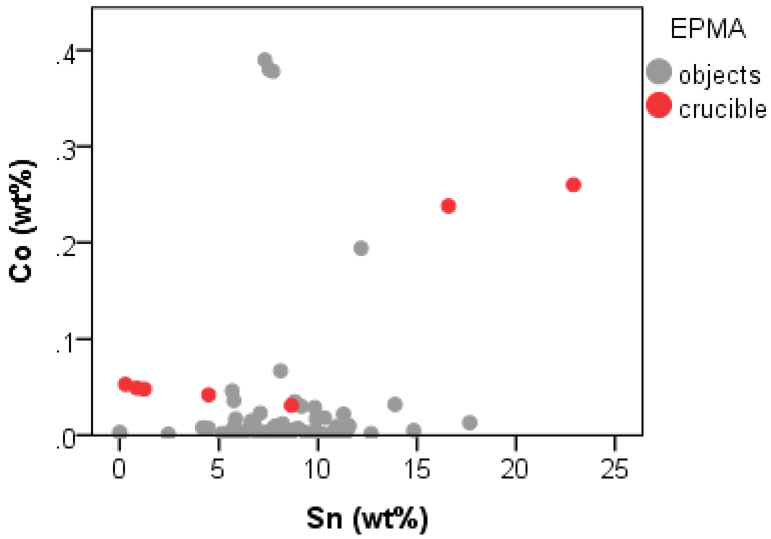


Figure 6.19. Scatterplot of tin against cobalt for the objects and crucible fragment analysed with the EPMA

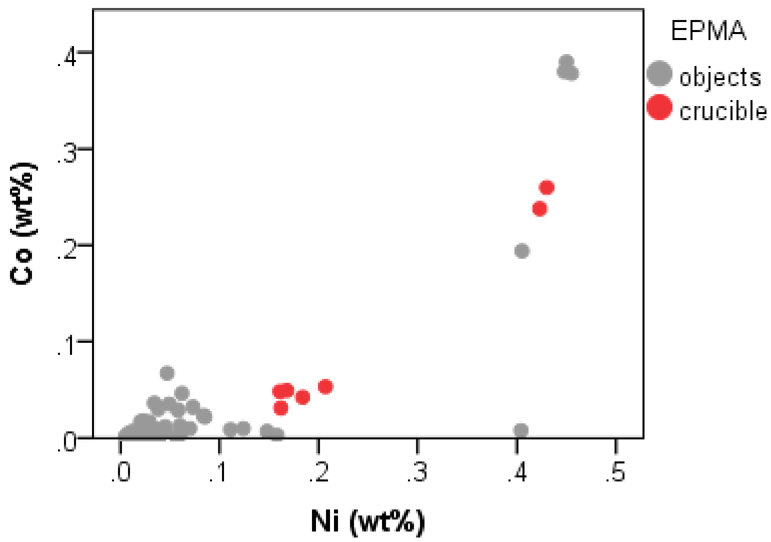


Figure 6.20. Scatterplot of nickel against cobalt for the objects and the crucible analysed with the EPMA

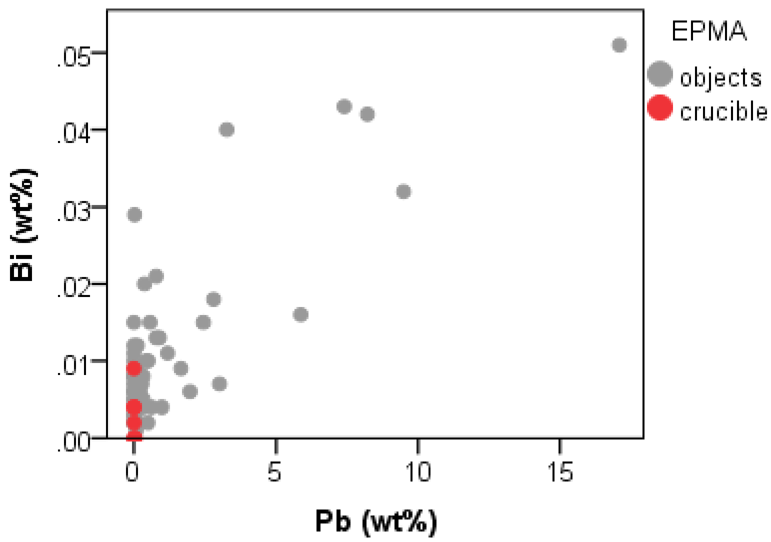


Figure 6.21. Scatterplot of lead against bismuth for the objects and the crucible fragment analysed with the EPMA

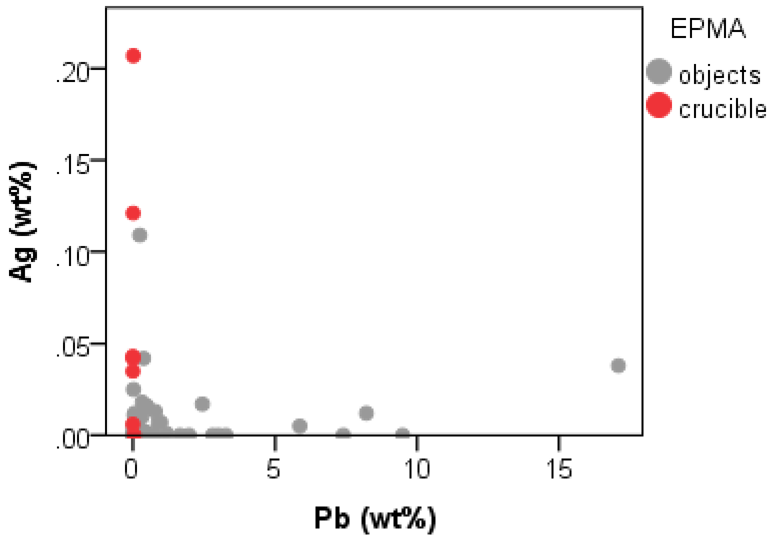


Figure 6.22. Scatterplot of lead against silver for the objects and the crucible fragment analysed with the EPMA where no correlation between the two elements is visible

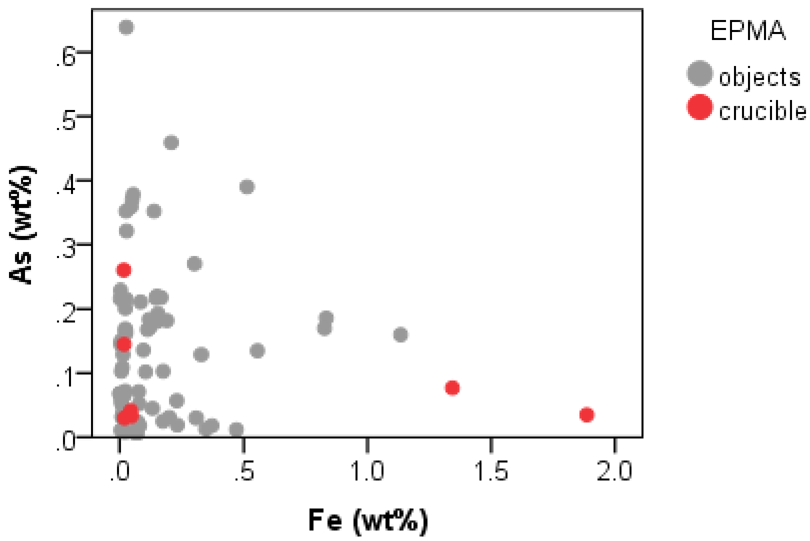
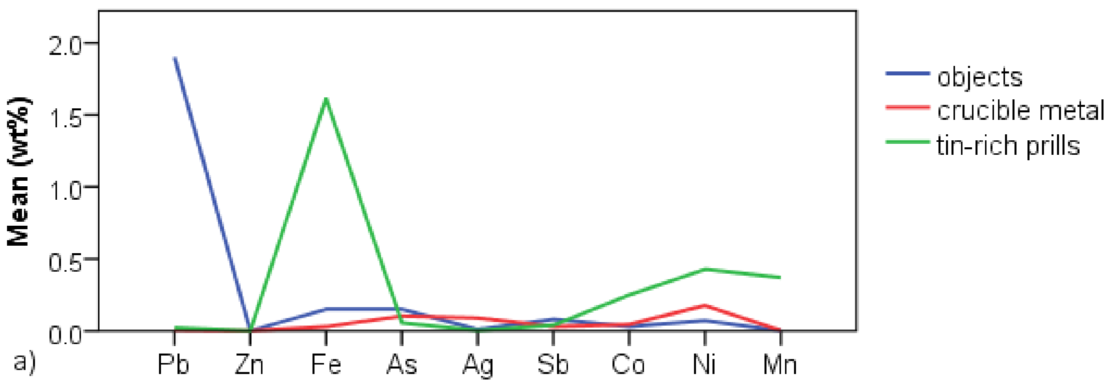


Figure 6.23. Scatterplot of iron against arsenic for the objects and the crucible fragment analysed by the EPMA



a)

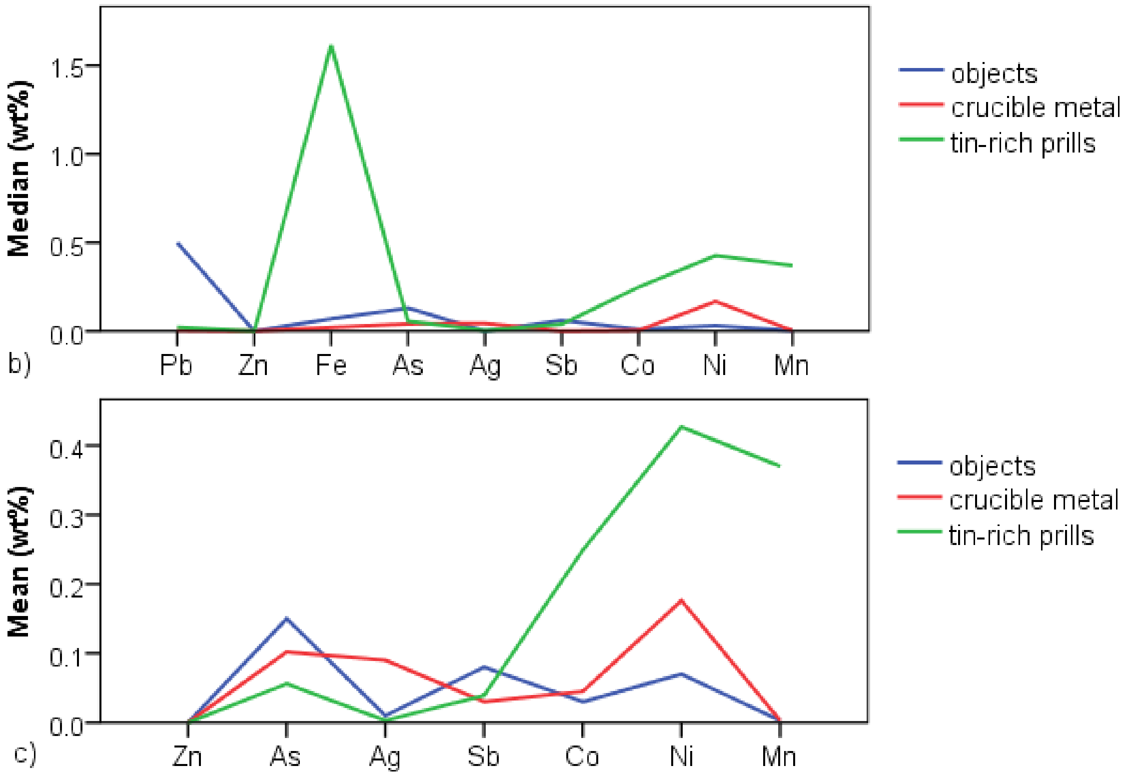


Figure 6.24. Line graphs for (A) the mean and (B) median values for the trace elements in the objects, the crucible metal and tin-rich prills as analysed by the EPMA, and (C) mean values for the trace elements with concentrations <0.4 wt%

In the light of the above discussed evidence, it is argued that the two clusters for the nickel and cobalt values do not necessarily point to different regional workshops, but rather to different phases of the same technological operations. Furthermore, typically low values for the trace elements including these for iron (Figure 6.18) or lead found for the metal in the crucible fragment suggest that rather clean, good quality copper-based alloys were produced at Pherae at least during the Archaic period. Such alloys would have been durable and suitable for intense metalworking. Finally, comparable trace element concentrations between the objects' assemblage and the bronze analysed in the crucible fragment point to the local production of copper-based artefacts to cover the needs of the Pheraean community and its nearby sanctuary and possibly to the supply of local ores.

Chapter 7. Manufacturing artefacts and making choices

Following the discussion of the alloy composition of the Pheraean sample, artefact typology and metalworking techniques are considered in detail below. Cross-investigation of qualitative and quantitative results aimed to explore the relationship between the manufacturing processes and artefacts' various functions and, thus, to reveal aspects of craft specialisation and the technological choices practiced during the copper-based production of Early Iron Age Greece. The cultural aspects that often play a decisive role during metal production such as the objects' design and decoration, use, value and/or colour have been also discussed along with certain technological attributes as seen during the microscopic and quantitative analyses. The following discussion of the metalworking techniques has focused on the EPMA dataset (n=70) since a cut fragment of the object was needed for the metallographic examination, whereas the entire sample has been considered in the discussion of the artefacts' typology and their bulk chemical composition (pXRF and EPMA, n=282). Issues explored below include standardization and control over the production process, and the technological choices that took place during the objects' manufacturing.

7.1 Defining metalworking practices

During the microscopic investigation the metal's overall microstructure as seen in the embedded samples was explored. Particular attention was paid to certain micro-morphological features such as the shape and size of the metal grains, dendrites or α grains, and the presence and the distribution of any metallic or other inclusions, e.g. sulphide inclusions or lead prills. Identification of the metalworking techniques employed such as repeated steps of hot- and cold-working (annealing) was primarily based on the investigation of polygonal, recrystallised metal grains with or without slip lines and annealing twins, as well as on the morphology, shape and size of sulphide inclusions and lead prills. Furthermore, samples' metal core and surface/substrate layers were examined and compared in order to discuss possible surface treatments employed in order to enhance the objects' colour properties. Finally, the samples' preservation state and the corrosion products which either accumulated on the objects' surface (see below 'patina') or replaced sound metal were identified.

7.1.1 Corrosion patterns

Examination of the corrosion features established the objects' preservation state, but it also revealed features of the original uncorroded metal microstructure. Corrosion products either in the form of inter- and intra-granular or benign corrosion patterns have often preserved the objects' original morphological characteristics such as in the form of 'ghost structures' (Figure 7.2 & Figure 3.16) (Oddy and Meeks 1982). Furthermore, the objects' original surface has been preserved by a thin corrosion layer ('patina') of cuprite and malachite (Figure 7.1 & Figure 3.18) (Scott 2002, p. 11). The presence of tin in the alloys tends to stimulate the formation of such passive, protective layers of corrosion, whereas the presence of small lead concentrations would typically not modify this pattern (Gerwin *et al.* 1998, Robbiola, Blengino, *et al.* 1998). In addition, sulphide inclusions tended to be preserved in corrosion layers (typically benign corrosion) even when all metal around them has been substituted by oxide or chloride compounds (Figure 7.3). At the same time, inter- and intra-granular corrosion, i.e. corrosion around and throughout the metallic grains, has often highlighted the metallic grain microstructure of certain samples, acting almost as natural etchant, and has, thus, made possible the identification of traces of specific metalworking operations (Figure 7.11) and annealing twins/slip lines (Figure 7.12). Nonetheless, this is not always the case since the presence of certain corrosion products such as basic copper chlorides is often responsible for the complete replacement of metallic grains by oxides and chlorides that have severely distorted the original metal microstructure, i.e. destructive corrosion patterns (Figure 7.4) (see also Chapter 3.2.3).

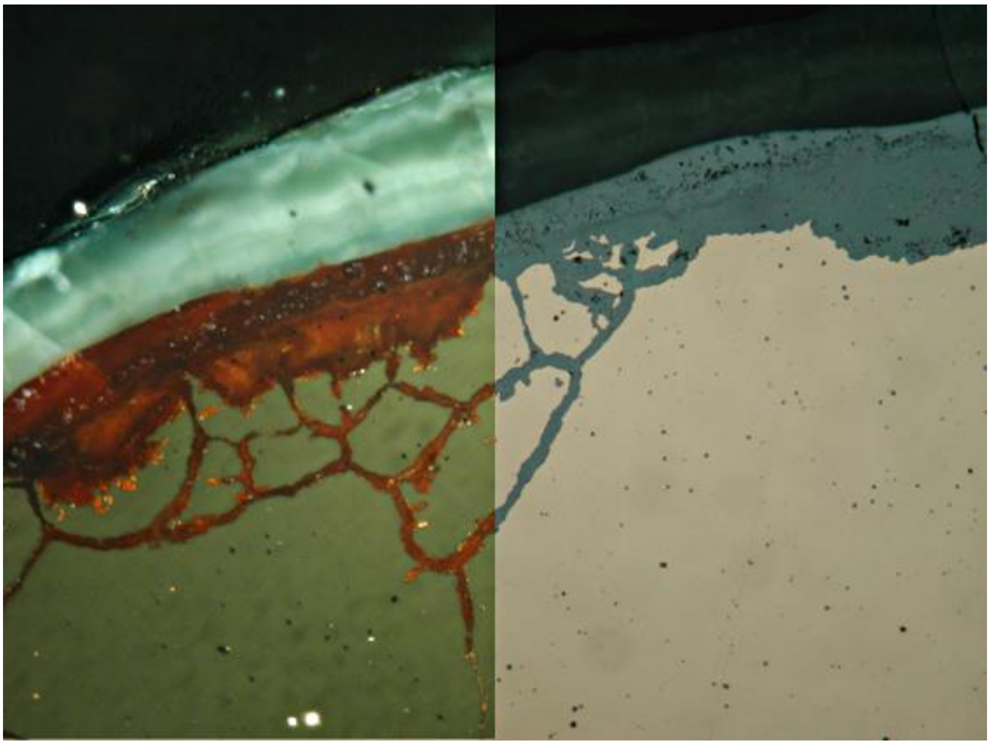


Figure 7.1. Photomicrograph of ring AE 810 under (right) PPL and (left) XPL where the ring's original surface has been preserved under a thin layer of basic copper salts (green on XPL), whereas the substrate has been substituted by cuprite (red on XPL); 500x, image width 350 μm

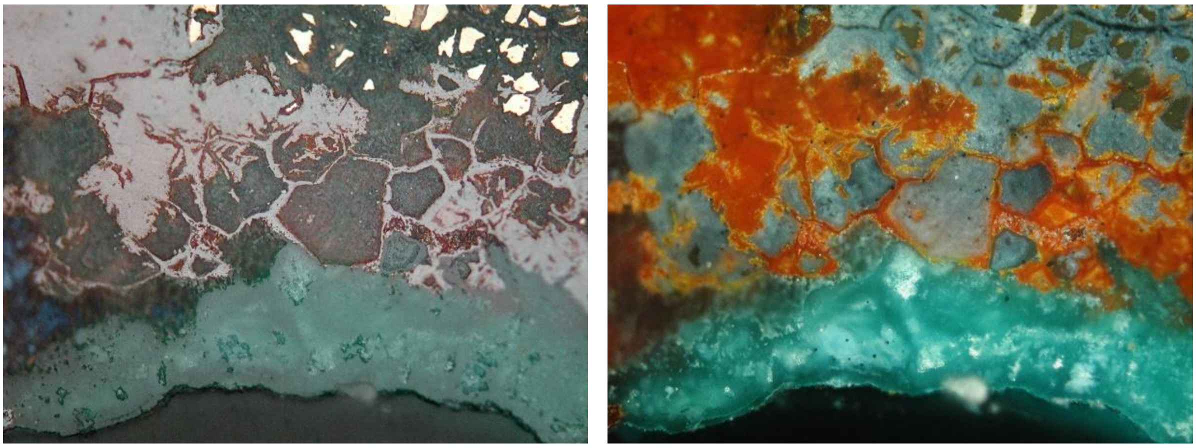


Figure 7.2. Photomicrographs of ring AE 624 where the outline of metallic grains is visible in the corrosion products; (left) PPL and (right) XPL, 500x, image width 350 µm

Figure 7.3. Photomicrographs of ring AE 651 (left) and metal sheet AE 743 (right) where elongated sulphide inclusions (black spots) are visible in the corrosion matrix (cuprite and basic copper salts); XPL, 500x, image width 350 µm

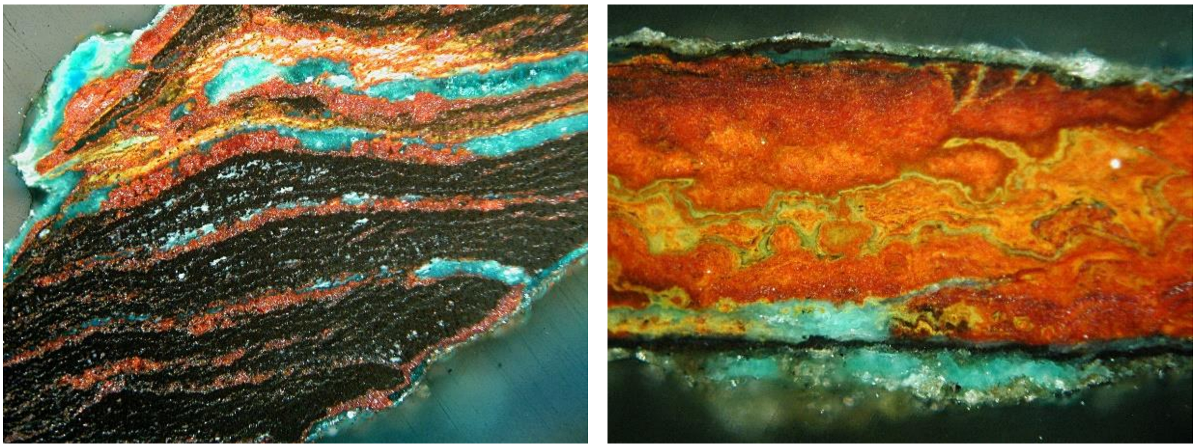


Figure 7.4. Photomicrographs of (left) fibula M 1652.1 (XPL, 100x, image width 1.8 mm) and (right) metal sheet AE 689 (XPL, 200x, image width 0.85 mm) where corrosion products have severely distorted the original metal grain microstructure; a lamellar corrosion pattern is seen in M 1652.1

7.1.2 Limitations and potentials of the sample's metallographic analysis

Below issues regarding the sampling strategy and the nature of the objects themselves are acknowledged for a more comprehensive interpretation of the metallographic observations. Amongst the first points to note is that only a very small area of the whole object is examined each time which might not be representative of the whole object. Even though the above would have not been a significant problem with small objects consisting of a single metal piece such as in the case of rings or metal sheets, it ought to be further discussed in the case of more complex and typically larger artefacts such as the fibulae or animal pendants which could have been produced by putting together different metal parts possibly made with different techniques and even compositions. A characteristic example to illustrate the above is indicated by certain fibulae types for which even macroscopically it is noted that they have been formed by joining together different pieces. For instance, the Epirotic and Thessalian bow types would have been manufactured by individually shaping their substantial cast bow and the hammered catch-plate, arm or foot, and then assembling them together (see also below Chapter 7.3.1). Hence, it worth noting that cut fibulae samples have been usually removed from the bottom part of the arm or the fragmented tips of the catch-plate or the foot, whereas pXRF analyses on fibulae in most occasions took place on the bow (Figure 7.5). Moreover, certain artefact types that were not found suitable for invasive sampling are under-represented in the metallographic analysis. Consequently, more samples have been cut from rings and metal sheets since these types of objects were often found fragmented with open ends that could have been easily cut by little affecting the physical integrity of the sample as opposed to complete pendants or fibulae, or other large castings.

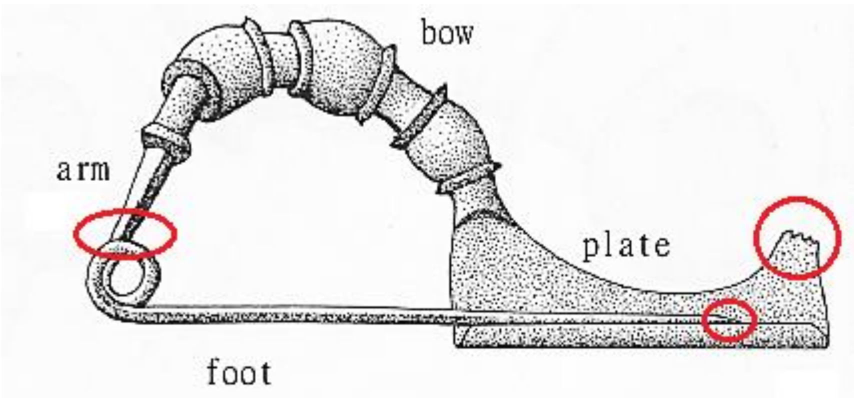
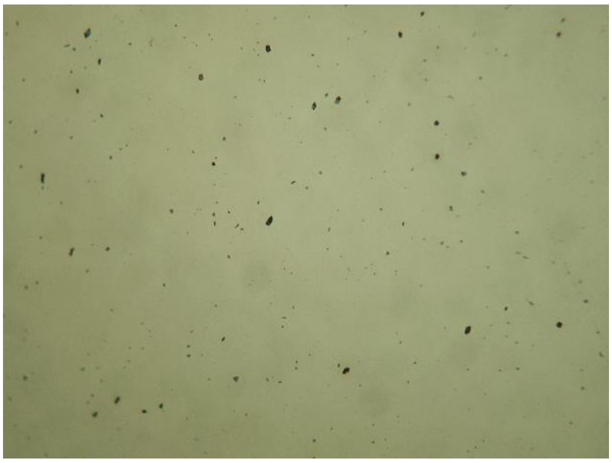


Figure 7.5. Thessalian fibula and its composite parts, i.e. the bow, plate, foot, and arm, where the areas that have been typically sampled from the fibulae in the assemblage are indicated by the red circles (after Kilian, 1975, pl. 12, no. 334)

In addition, the way the samples themselves have been embedded in the resin blocks also needs consideration. A cross section (at right angle to the long axis) and a radial or tangential section (parallel to the long axis) of the same object could reveal different features of the metalworking operations. This is, for example, well-illustrated when different sections of two rings that are typologically almost identical are considered. Type Ia Rings AE 103 and AE 113 (see Appendix I) from which a cross- and a tangential section were embedded respectively revealed different characteristics of the metalworking practice. For instance, in the cross section of ring AE 103 sulphide inclusions are visible in the metal but only in the tangential section of AE 113 the deformation of these elongated inclusions by repeated hammering is visible (Figure 7.6). Meanwhile, a similar pattern is seen in the tangential section of metal sheet 1308 (Figure 7.10).

a)



b)

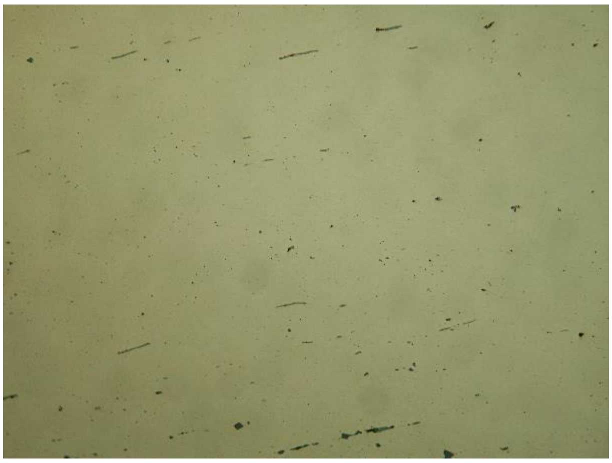


Figure 7.6. Photomicrographs of (A) cross section of ring AE 103 and (B) tangential section of ring AE 113; PPL, 500x, image width 350 µm

7.1.3. Metalworking groupings

In order to explore the intensity of the metalworking operations that took place during the objects' shaping four distinct categories have been identified. These further explore the relationship between specific metalworking choices and the different degrees of time- and skill-investment with the alloy recipes used and the artefact types themselves. The four metalworking categories have been defined as (A) as-cast, (B) slightly worked, (C) worked, and (D) intensively worked structures. The above grouping aimed to cluster together objects which were not necessarily produced with an identical set of metalworking steps, but rather to establish different degrees of metalworking intensity. Meanwhile, the different degrees of skill, effort, and labour investment on the part of the metalsmiths would have possibly added further to the value of the alloy used itself.

A. *As-cast* objects are primarily recognised on the basis of certain microstructures defined by the presence of dendrites and/or α grains which would have formed in sympathy with the alloy composition and cooling rate (Figure 7.7).

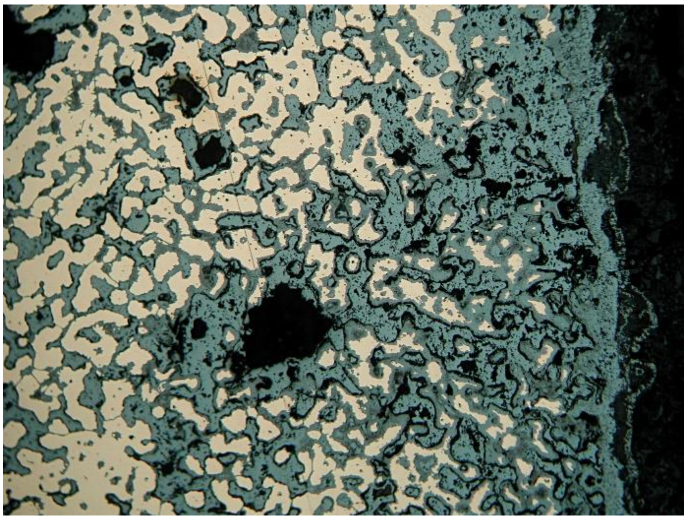


Figure 7.7. Photomicrograph of sheet/vessel fragment AE 606 where a dendritic structure is visible surrounded by corrosion products; PPL 100x, image width 1.8 mm

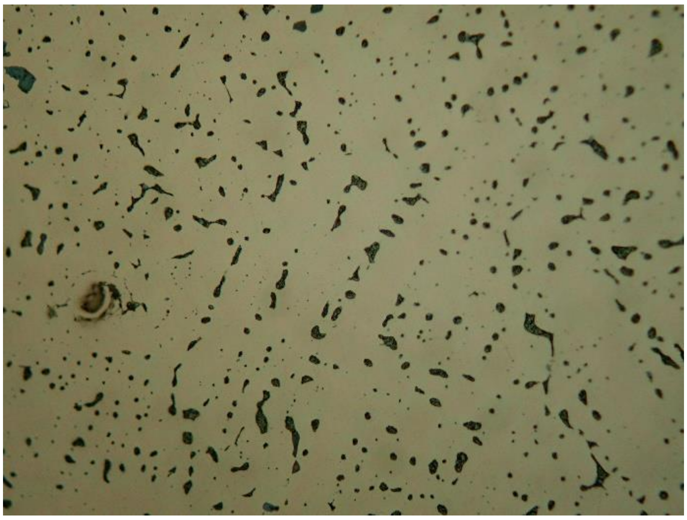
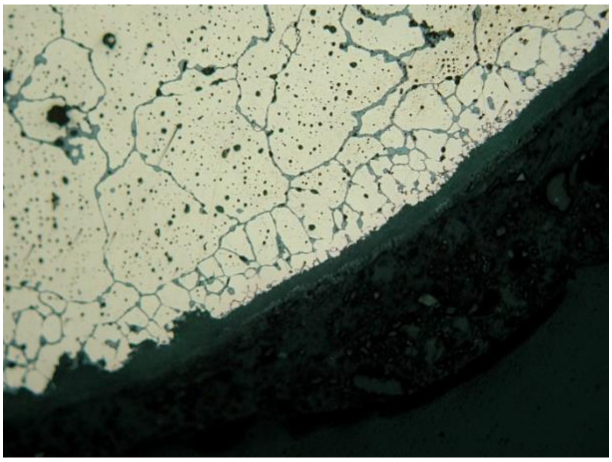
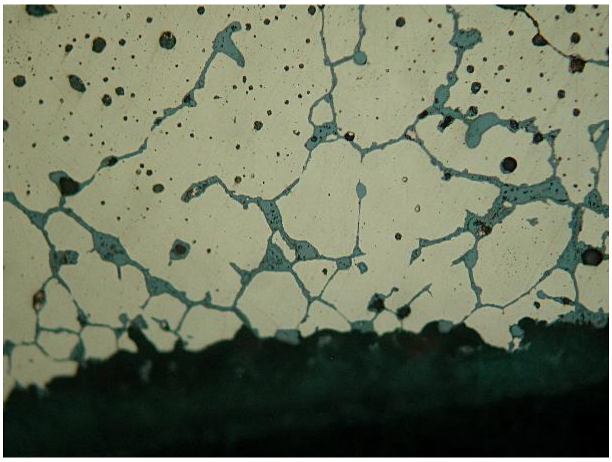


Figure 7.8. Photomicrograph of ring 1310 where a dendritic structure is visible; the dendrites' core has a rather red colour, characteristic of copper, which is defined by more yellow areas where higher tin amounts have accumulated; lead prills have concentrated between the dendrites boundaries (8% Pb); this structure has formed as the result of different cooling and solidification temperatures of the metals present in the alloy; PPL, 500x, image width 350 μm

B. As *slightly worked* were classified samples which present a combination of as-cast features, usually towards the object's metal core, and traces of mild metalworking and annealing (repeated cold- and hot-working) such as few polygonal grains often with an equiaxed structure typically closer to the objects' surface and substrate (Figure 7.9). Objects in this category have been cast first and have then undergone mild metalworking in order to bring to the desired shape and finish.



a)



b)

Figure 7.9. Photomicrographs of ring AE 564 with 6% tin and lead traces where a rather worked/treated surface with somewhat polygonal grains with fewer inclusions and gas-holes (right) is seen over an as-cast core consisting of α grains; (A) PPL, 200x, image width 0.85 mm, (B) PPL, 500x, image width 350 μm

C. *Worked* objects are characterised by distinct recrystalised, polygonal and/or angular microstructures throughout the sample as a result of laborious hammering and hot-working (annealing) (Figure 7.10). They typically have large metallic grains in comparison to the next category with few strain lines.

D. Finally, the fourth group of *intensively worked* objects shows a quite distinct pattern of rather small metallic grains with plenty of slip planes and the characteristic annealing twins (Figure 7.11). In this case, the metal would have been cold-hammered in order to shape and harden, and then heated in order to recrystalise the stressed grains and to decrease brittleness.

Repetition of the above sequence of operations would have produced a hard and durable object. Finally, sulphide inclusions in both the worked and annealed groups have a characteristic elongated shape and are often angular as a result of the mechanical stress caused by the hammering (Figure 7.10 & 7.13).

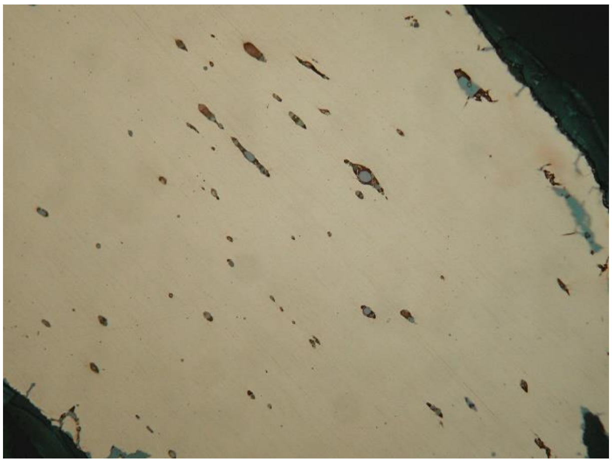


Figure 7.10. Photomicrograph of tangential section of unalloyed copper sheet 1308 with lead traces where deformed inclusions from repeated hammering are visible; PPL, 500x, image width 350 μm

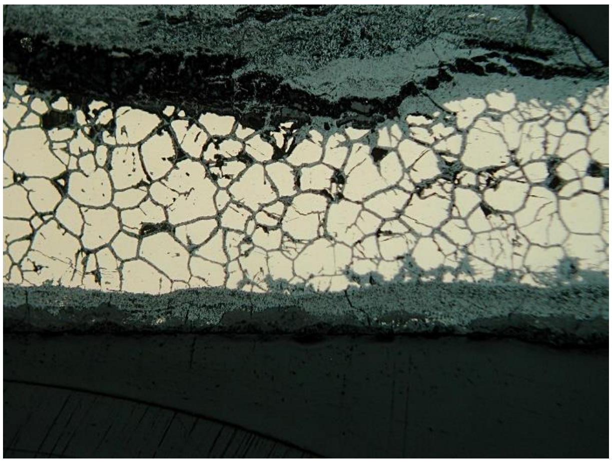


Figure 7.11. Photomicrograph of sheet AE 480 where polygonal/angular metal grains are visible as a result of annealing; PPL, 100x, image width 1.8 mm

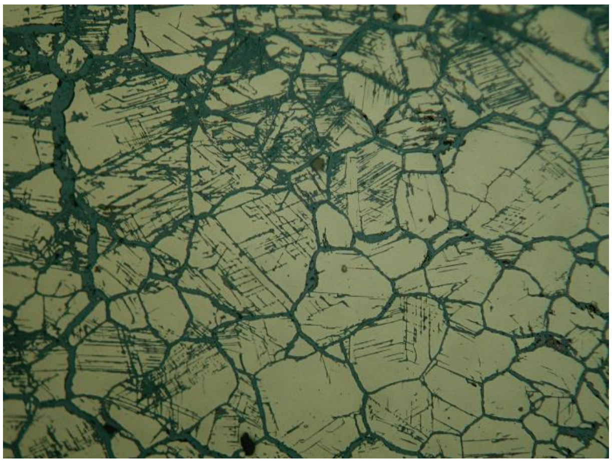


Figure 7.12. Photomicrograph of sheet M 1217.2 where a recrystalised grain microstructure with annealing twins and slip planes is visible; PPL, 500x, image width 350 μm

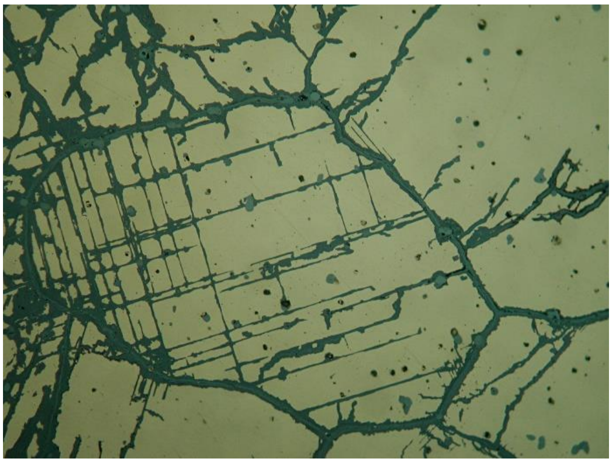


Figure 7.13. Photomicrograph of pendant M 2277 where strain lines highlighted by intra-granular corrosion products are visible within a stressed grain as a result of repeated hammering; PPL, 500x, image width 350 μm

7.2 Metalworking and composition at Pherae

Investigation of the sample's metalworking in conjunction with the compositional features and alloy recipes revealed characteristic patterns for the Pheraean assemblage. In the following discussion, the four metalworking groups as identified above (A to D) have been considered individually, but also clustered together into two broader groups which each included the objects with the little or intensive metalworking, i.e. as-cast/slightly worked (A/B) and worked/intensively worked (C/D) respectively. Grouping the objects according to the degree of labour investment allowed for the relationship between their metallographic and typological characteristics and the chemical compositions to be explored in more detail. This revealed information regarding the standardisation of the metallurgical process from the mixing of metals for the production of alloys to the particular metalworking habits applied during the different stages of the objects' production. Further grouping of the assemblage into the two categories, namely A/B and C/D, allowed for any emerging patterns to be discussed by focusing on the bigger picture rather than the particularities of individual samples. Discussion of this broader clustering is further justified due to the fact that very few objects have been identified with an as-cast structure and, also, that boundaries drawn between each metalworking category (A to D) may not be clear cut due to the small sample size along with the operation of selective action of corrosion products which played a decisive role in highlighting the different metallographic features (see also above this Chapter 7.1.1).

Metallographic investigation showed that characteristic patterns emerge for as-cast and worked objects, while an overall preference for hammering and annealing over casting is seen (66 out of 70 objects). Only four samples have provided evidence of purely as-cast structures where no (or at least not traceable during present analysis) further metalworking took place (Figure 7.16). Looking at the tin and lead distribution for the little (A/B) and intensively worked (C/D) objects, greater dispersion of values for both elements is visible for the former whose values cluster around a 5-12% binary tin bronze often with noticeable lead impurities as opposed to the latter which overall showed smaller standard deviation values both for tin and lead (Figure 7.14a, 7.15 & Table 7.1).

Table 7.1. Mean tin and lead values for the different metalworking groups

	A - as-cast (n=4)		**B - slightly worked (n=19)**		**C - worked (n=27)**		**D - intensively worked (n=20)**	
	Sn	Pb	Sn	Pb	Sn	Pb	Sn	Pb
Mean	9.9	4.0	6.8	2.2	8.0	0.5	10.1	0.2
Std. Dev.	5.2	4.4	3.5	4.3	2.0	1.2	2.4	0.3

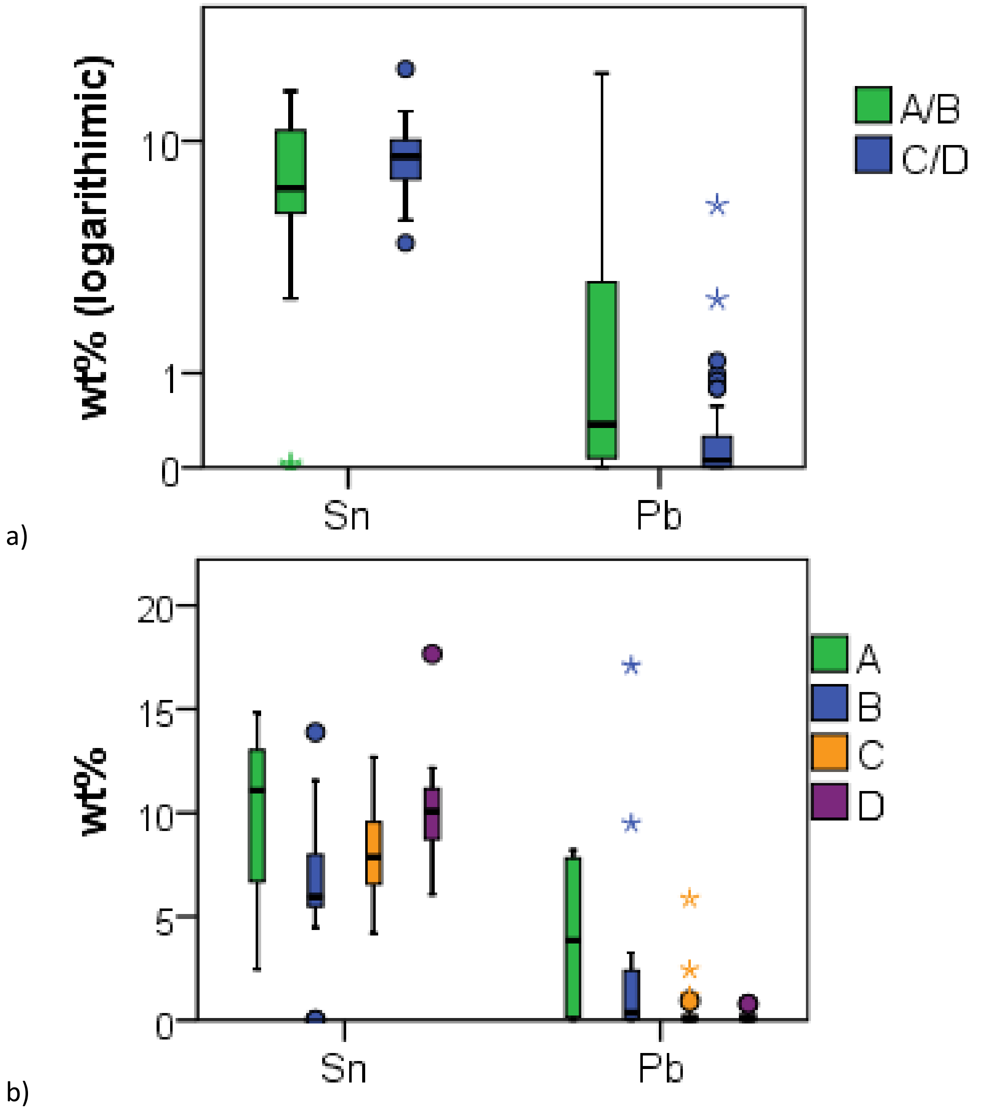


Figure 7.14. Five point boxplots for the tin and lead contents according to metalworking technique from as cast (A) to intensively worked (D)

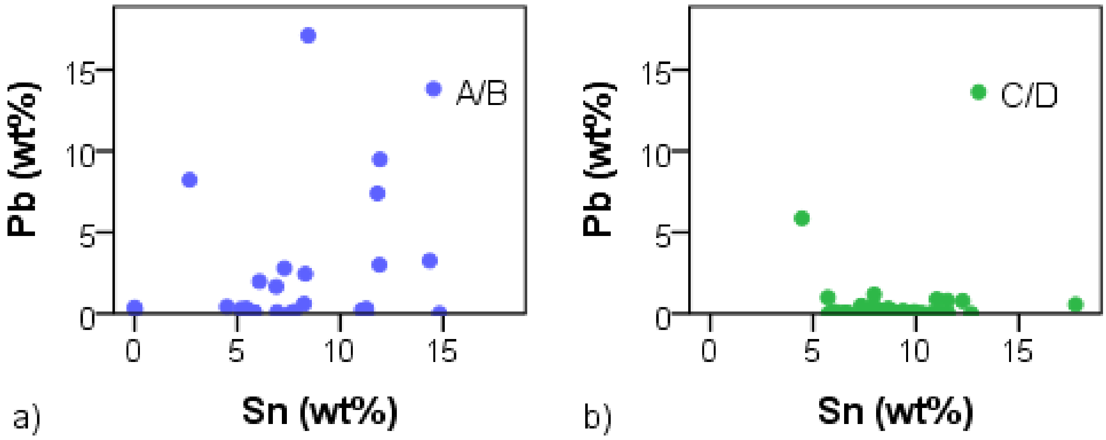


Figure 7.15. Scatterplots of tin (renormalised) against lead for (A) the as-cast/slightly worked (A/B) and (B) worked/ intensively worked (C/D) objects in the sample (EPMA, n=70) where more tightly clustered values are seen in the C/D group which is typically lead free

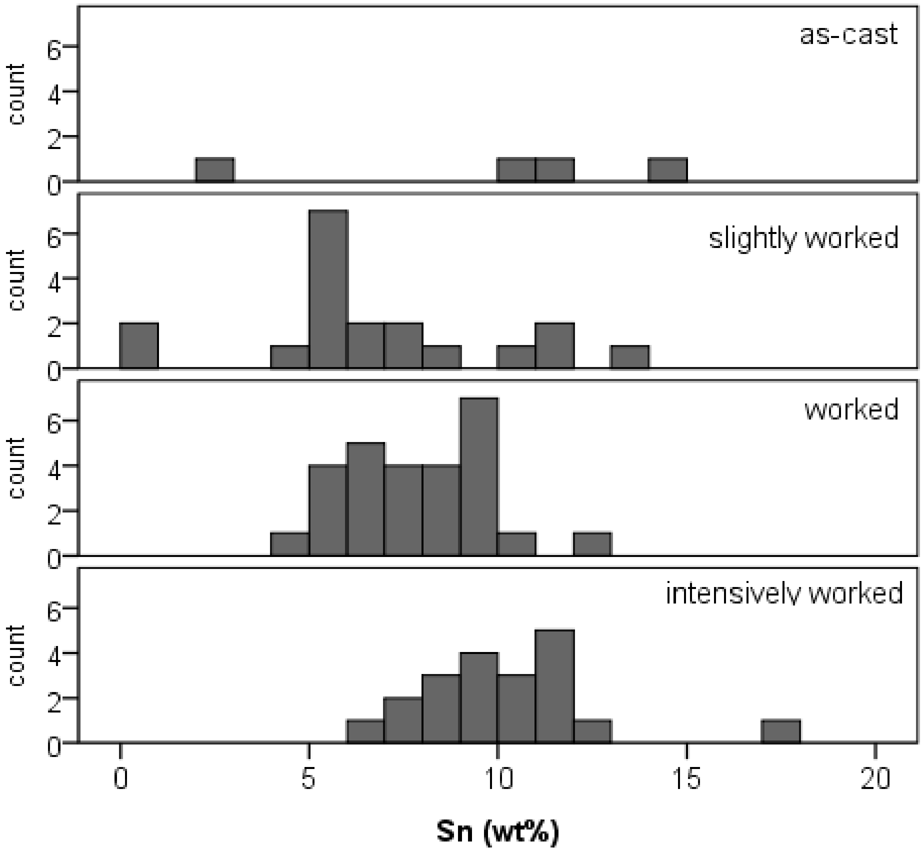


Figure 7.16. Histograms of the tin distribution for the different metalworking groups

The four metalworking groups showed a pattern where average tin values are positively correlated with the amount of labour invested in each sample is seen. Thus, more tin is typically found in the intensively worked (D) group with the worked (C) and slightly worked (B) groups following with respective mean tin values of 10%, 8% and 7% (Figure 7.14b & 7.16). In addition, the worked and intensively worked groups showed lead only as an impurity with average values below 0.5% lead, whereas only one outlier with 6% lead was analysed (Table 7.1, Figure 15b). The apparent absence of leaded objects in the worked groups could be further justified by the effect that lead additions to copper or tin bronze would have had such as they would have rendered the metal softer and more prone to cracking particularly upon intense metalworking (Scott, 1991) (Figure 7.18).

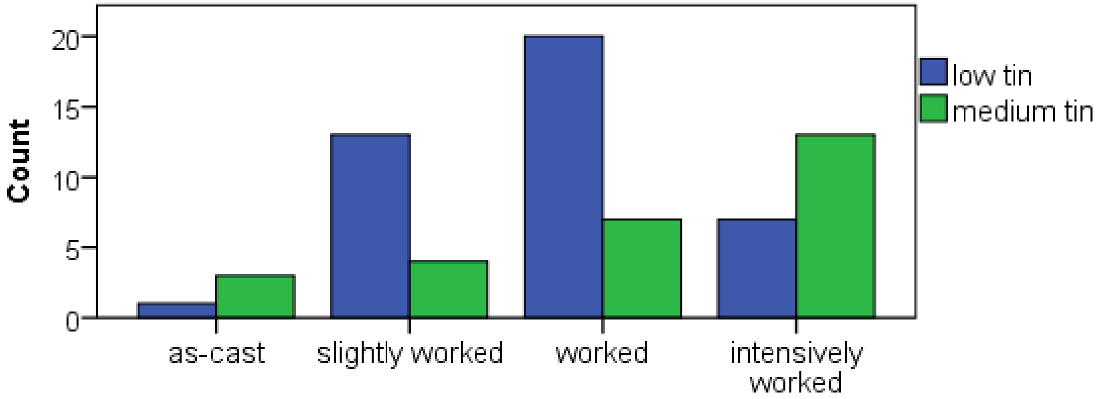


Figure 7.17. Barchart showing the relationship between the low and medium tin bronze alloys and the metalworking techniques employed during the objects' production

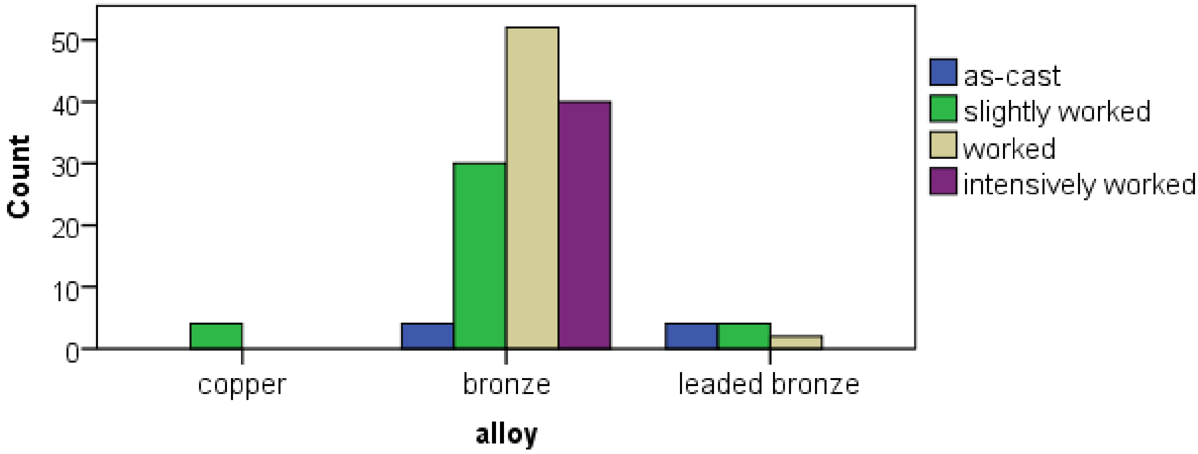


Figure 7.18. Barchart of metal/alloy recipes according to the metalworking technique

Despite the tendency for higher tin values to be correlated with the more intensively worked objects (C/D) there is no clear-cut division between the metalworking techniques and the low or medium tin groups as discussed in Chapter 6 as both recipes were found in seen in all four metalworking groups (Figure 7.17). Nonetheless, the group of intensively worked objects (D) was also the only group where higher tin values (the medium tin group) were most often found. Finally, the correlation between the amount of tin added and the effort put in the shaping of the object could be further justified by the nature of the tin-rich alloys themselves. High tin contents in copper would have rendered the metal harder to shape and, thus, more laborious working and annealing would have been needed in order to bring objects to the desirable shape.

7.3 Artefact use, typology and technology

Following the discussion of the metalworking techniques in relation to the mechanisms of metals mixing and alloy recipes, quantitative and qualitative data have been brought together with artefact typology and use to discuss choices during the copper-based production. This exploration of the relationship between the macroscopic, metallographic and compositional features of the copper-based objects allowed for aspects of technological specialisation and decision making to be identified.

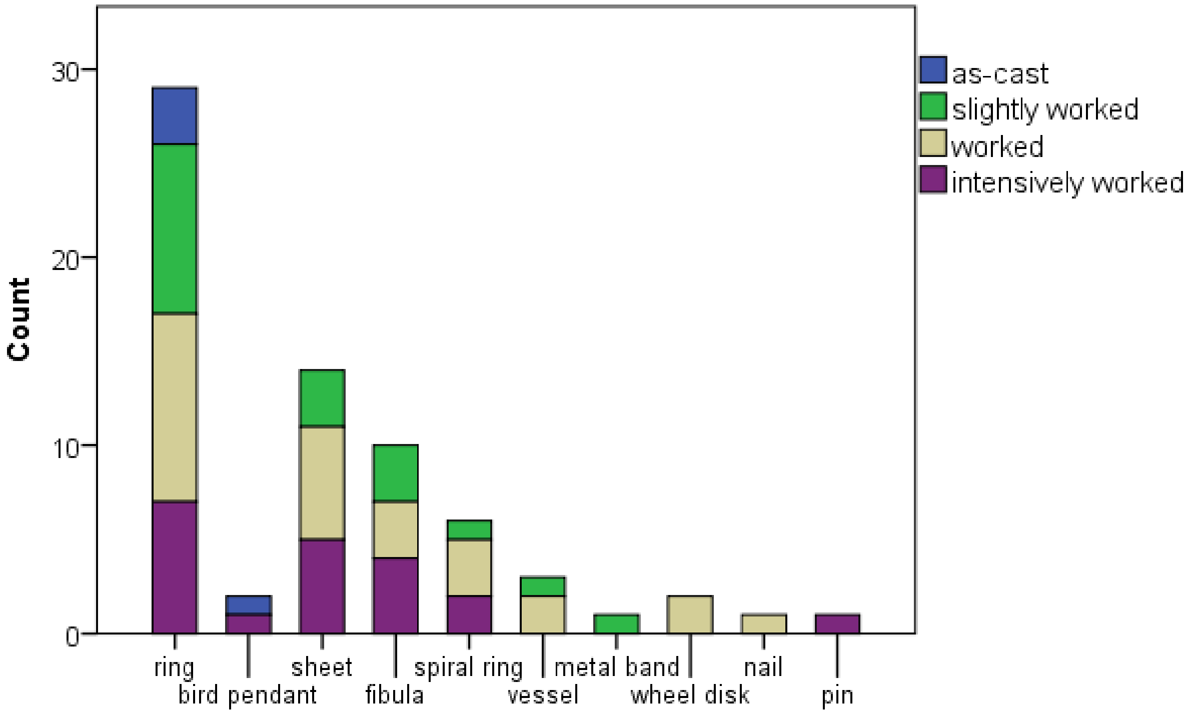


Figure 7.19. Barchart of artefact types in the sample according to metalworking technique

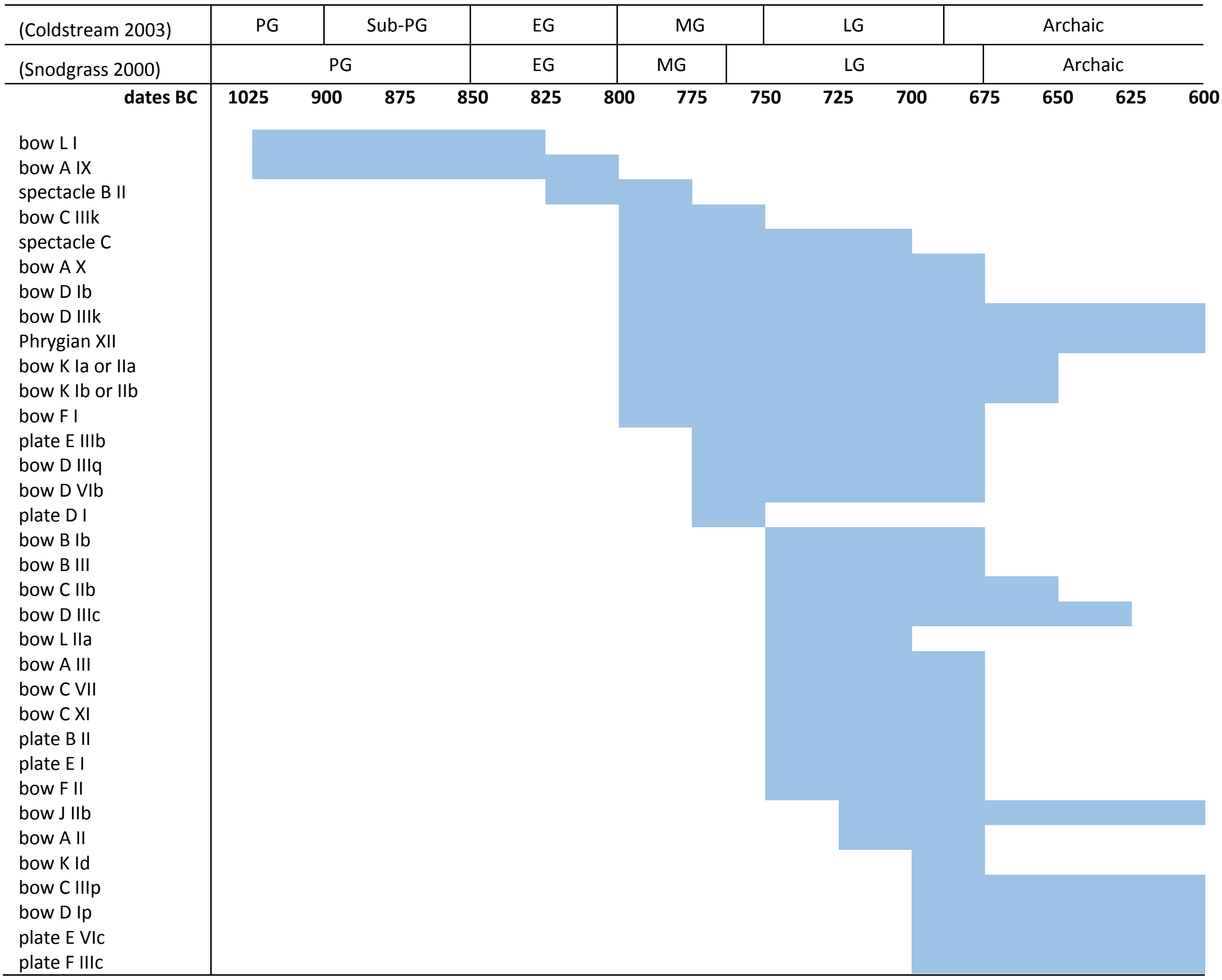
As with the low and medium tin groups, metalworking groups within and across the artefact types showed no clear correlation with the artefact types as a range of techniques have been employed in the production of each artefact type. For example, fibulae, rings and sheets have been classified in all B, C, and D metalworking groups (Figure 7.19). Nonetheless, certain trends have been noted such as that intense hammering and annealing was typically identified amongst all the different artefact types used in personal adornment, such as the rings, spirals, fibulae and the pin. In addition, these objects possibly intended to be worn regularly would have experienced significant mechanical stress and, thus, hardening and increasing their durability by recrystalisation via annealing steps can be justified. Finally, in the case of jewellery more tin and meticulous metalworking would have also enhanced their colour too. The metal sheets' particularly thin cross-section, often not thicker than 1 or 2 mm, could justify the repeated hammering in order to produce such thin metal sheets, while a single bird pendant analysed is not sufficient to argue further for particular preferences during this artefact group manufacturing. Similarly, the rest of the artefacts examined microscopically, including two fragments from vessels (one from the body and another from the rim of different vessels), a metal band, a wheel disk pendant, and a nail are not sufficient to promote a more detailed discussion of their metalworking.

Below, the aforementioned artefact types with several occurrences in the sample, namely the fibulae, rings, sheets and pendants, are discussed in more detail in order to examine the relationship between form, composition, and metalworking.

7.3.1 Fibulae

The fibulae constitute the largest artefact group in the Pheraean assemblage, as well as in the sample as they form 42% of all the objects analysed (119 fibulae) (Table 3.1). This group is represented by several types and subtypes which have been examined by Kilian (1975) and Blinkenberg (1926). Nonetheless, Kilian's categorisation has been more detailed in that it was not only based on their design in order to assign them broadly to cultural traditions or regional workshops such as central/northern Greek, Near Eastern, Italian, or Balkan, but it also dealt with additional features of the fibulae such as their size or small variations in their decoration within a certain category, the particular shape of the catch-plate, or the bow's arch shape. For instance, the fibulae M 1909 and M 757 which both belong to the Thessalian tradition have been assigned to different subcategories due to the different form of the globules on their bow (Figure 7.20a & b). Furthermore, fibulae M 1909 (Figure 7.20a) and M 226.1 (Figure 7.29) which are both of the Thessalian type and also share the same bow decoration, have been further subdivided by Kilian to two distinct categories, i.e. D Ip and D IIIq, due to their different size since fibula M 226.1 is double the size of a typical fibula (Kilian, 1975, pl. 13 & 24). Such detailed categorisation and subdivision of the fibulae allowed Kilian to discuss the evolution of certain fibulae types which lead him further to establish a relative chronology for each fibula subtype from approximately the late 11th to the 6th century BC. These findings have been also used here to partly place the Pheraean assemblage in time as already discussed (see Chapter 3).

Table 7.2. The different fibulae types represented in the sample according to their types and subtypes (after Kilian, 1975; Blinkenberg, 1926) and their absolute and relative chronology (dates and chronological periods are for Thessaly after Coldstream, 2003; Snodgrass, 2000)



In the sample some thirty-five types and subtypes as defined by Kilian have been identified (Table 7.2). Based on Kilian's detailed exploration of the macroscopic characteristics of the fibulae, it was possible to group them under broad typological sequences which relate to distinct regional traditions including the Epirotic, Thessalian, Helladic (including the Attic-Boeotian type), spectacle (of northern Greek or Balkan origin), and Phrygian (Asia Minor and Anatolia) (Figure 7.20, Table 7.3). Nonetheless, this categorisation even though links to specific cultures or traditions, it does not relate directly to the actual production sites and workshops since similar art historical approaches often rely on presumptions and neglect the many recorded working sites in the archaeological record with *in situ* traces of primary or secondary production phases (Heilmeyer 2004, p. 412) (Figure 7.21). In light of the lack of evidence for the fibulae production sites, the above categorisation into wider groups, i.e. Thessalian or Epirotic, rather than in the subcategories which are represented each with only few samples, promoted the discussion of the particular technological characteristics and related patterns emerging across the different fibulae categories which would potentially reveal aspects of the respective technological traditions.

Figure 7.20. Different fibulae types represented in the sample: Thessalian (a – M 1909, b – M 757), Epirotic (c – M 1794, d – drawing after Kilian 1975, n. 1175, pl. 41), Phrygian (e – M 1413), Attic-Boeotian (f – M 2265), Helladic (g – M 338), and Spectacle (h – M 2222)

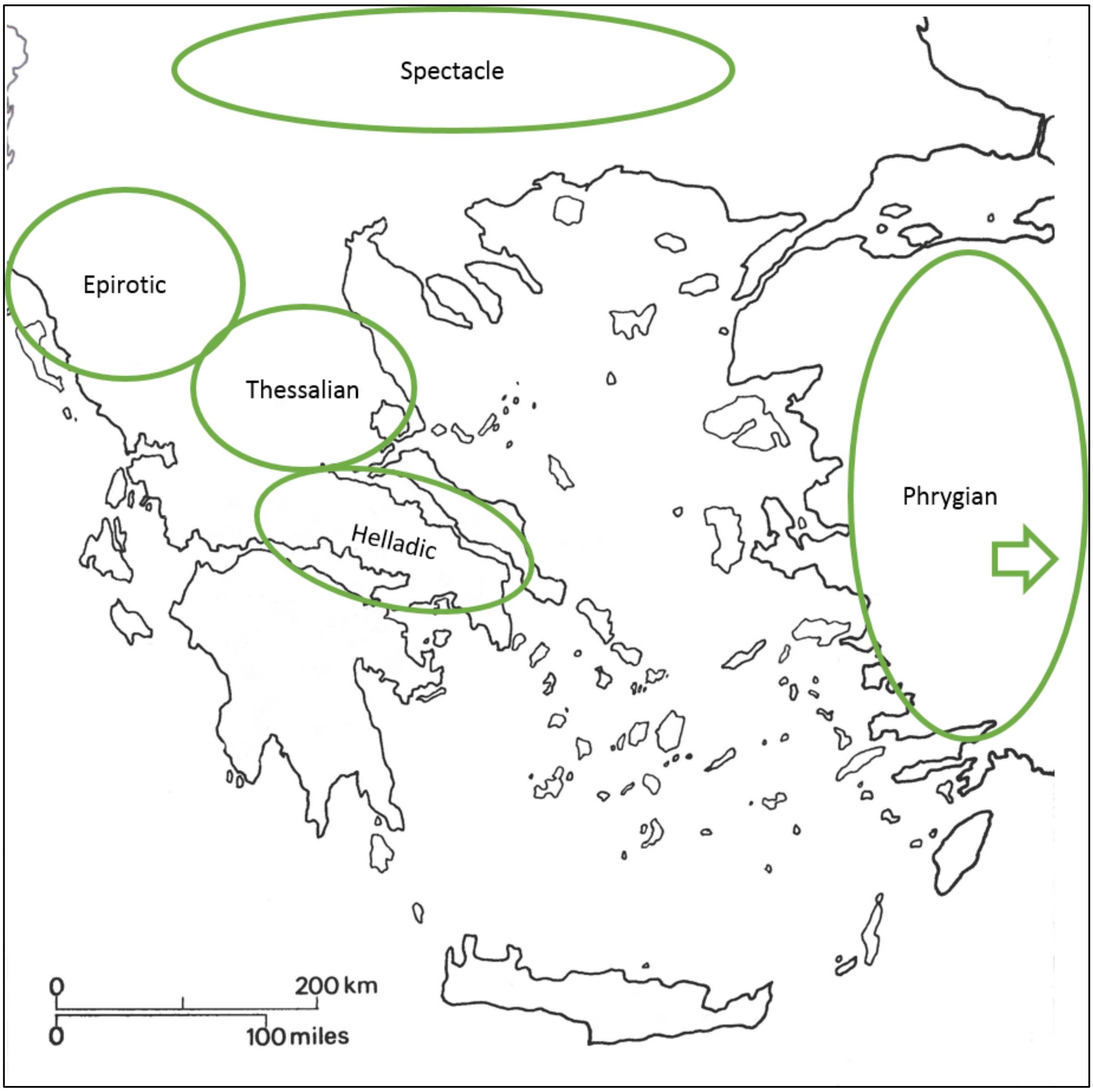


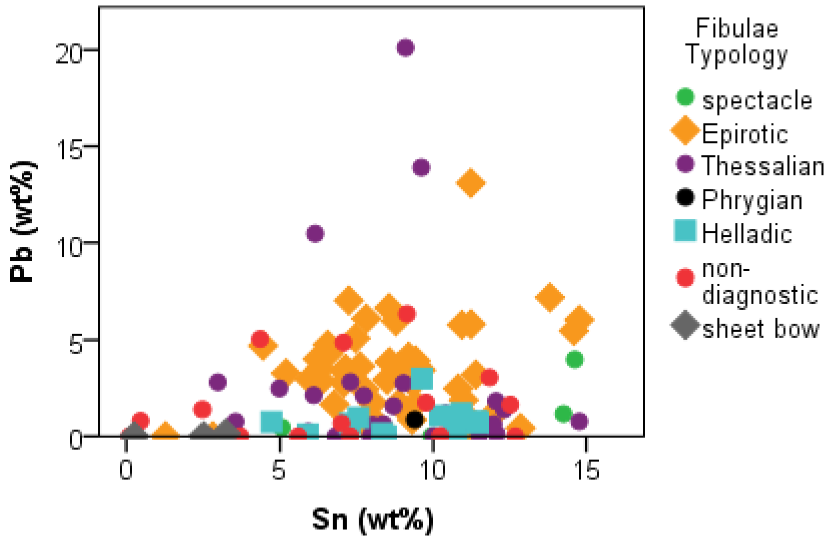
Figure 7.21. Map of mainland Greece, the Aegean, and Asia Minor where the different regional workshops to which the majority of the diagnostic fibulae in the sample have been attributed; geographical boundaries drawn in the map are approximate at best and are used here to provide a general sense of the fibulae groupings and their relationship to space

Hence, discussion of the fibulae focused more on the regional workshop groupings rather than on the different types and subtypes within these since neither their dating is clearly defined nor are the minor variations in their shape, decoration or size necessarily distinctive of different technologies. Six fibulae groups have been identified along with sixteen fragments undiagnosed due to their fragmentary state and bad preservation. The majority of the samples belong to the Epirotic, Thessalian, and Helladic types, while simple sheet bow, spectacle and Phrygian fibulae are represented with fewer samples. Investigation of the above groupings along with the large number of fibulae analysed allowed for the identification and exploration of possible patterns emerging across the different regional workshops in central and northern Greece and the techno-cultural choices exercised by the different metal object producing centres. This formed further a starting point for testing the hypothesis of different technological traditions practiced within respective geographical areas and/or cultures and communities, as well as the possibility of imitations produced locally as seen in the case of the bird pendants being imitated in Laconia (Voyatzis 1990).

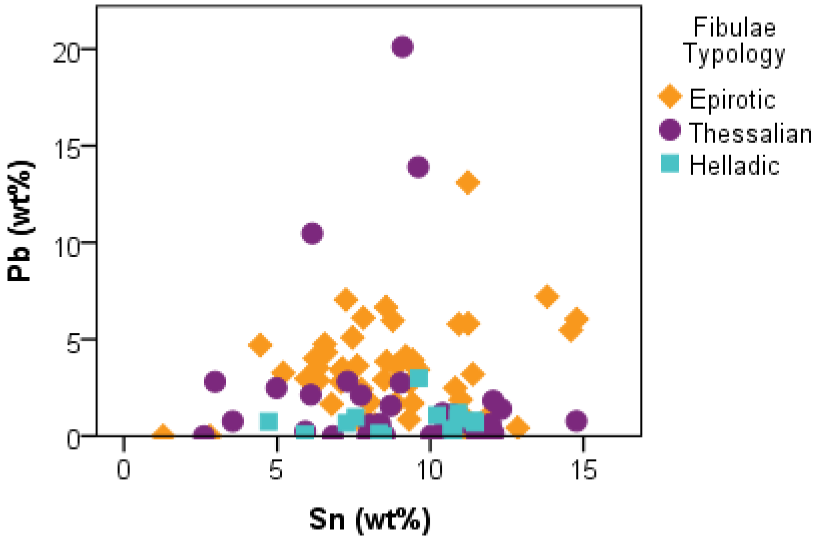
Out of the 119 fibulae in the sample, only ten have been examined with EPMA, while the rest were analysed non-invasively with the pXRF. This rather uneven distribution of the fibulae in the datasets is primarily linked to the nature of the artefacts themselves since not many fibulae were both fragmented which would allow to remove a sample from and well preserved enough in order to be attributed typologically. Non-invasive analyses was usually carried out either on the bow in the case of the Epirotic, Thessalian and Phrygian (Figure 7.5) or on the large square catch-plates of the Helladic and Attic-Boeotian fibulae (Figure 7.20f & g), whereas cut samples were mostly taken from the catch-plate, foot or the arm and spring of the fibulae. Since the EPMA dataset is rather small to be regarded as representative of the thousands of fibulae recovered or of the 119 fibulae in the sample, results for the major elements produced by both analytical techniques are combined below.

7.3.1.1 Typological traditions and technical characteristics of fibulae

The analysed fibulae (n=119) produced on the whole results comparable to those of the entire sample where mostly binary tin bronzes were found with tin values typically between 5% and 15% tin, along with fewer leaded artefacts with lead amounts largely below 8% Pb, and a handful of outliers with up to 20% lead (Figure 7.22a & Figure 4.2). Moreover, certain patterns seem to emerge amongst the different fibulae types.



a)



b)

Figure 7.22. Scatterplot of tin against lead for (A) all the different fibulae types present in the sample and (B) the three largest typological groups, namely the Epirotic, Thessalian and Helladic fibulae (EPMA & pXRF)

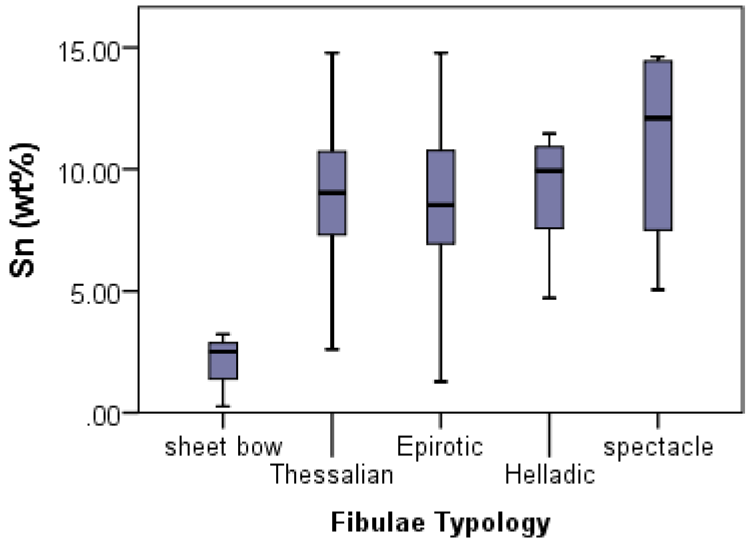


Figure 7.23. Five point boxplot for the tin content in the sheet bow, Thessalian, Epirotic, Helladic, and spectacle fibulae

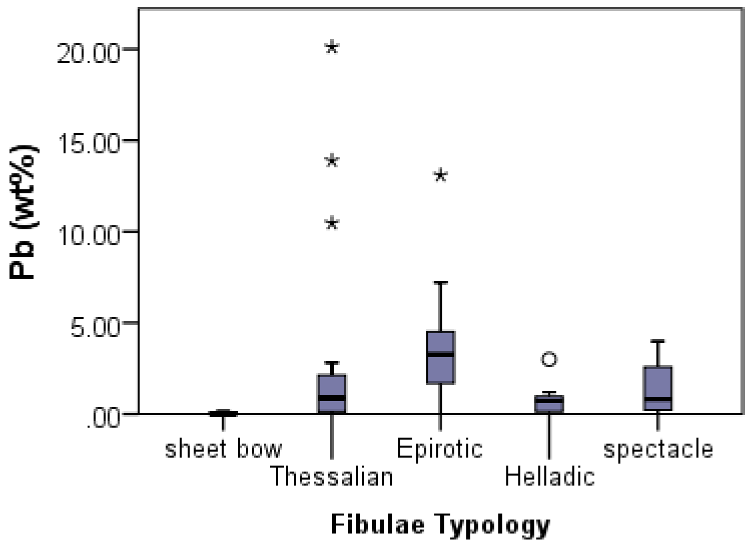


Figure 7.24. Five point boxplot for the lead content in the sheet bow, Thessalian, Epirotic, Helladic, and spectacle fibulae

Table 7.3. Tin and lead averages for the different fibulae types as analysed with both analytical techniques (pXRF & EPMA)

Fibulae Typology		Sn (wt%)		Pb (wt%)	
	N	Mean	Median	Mean	Median
Sheet bow	3	**2.0**	**2.5**	0.1	0.0
Non-diagnostic	16	6.5	7.0	1.6	0.7
Epirotic	51	8.7	8.6	**3.4**	**3.3**
Thessalian	30	8.7	8.9	2.4	0.9
Helladic	14	9.2	9.9	0.8	0.7
Phrygian	1	9.4	9.4	0.9	0.9
Spectacle	5	**11.1**	**11.5**	1.1	0.5

Tin content

The fibulae discussed here consist predominantly of binary tin bronze as suggested by average lead values which on the whole fall below 4% Pb, whereas only the group of sheet bow fibulae consists of unalloyed copper, namely the fibulae M 775 (Figure 7.25), M 776.1 and 776.2 (Table 7.3, Figure 7.24). Moreover, characteristic patterns were noted regarding the tin contents which further differentiate the respective fibulae typologies. Hence, the simple sheet bow fibulae provided the lowest mean and median tin values of just 2%, while the group of spectacle fibulae proved the richest in tin with average values of 11% tin (Figure 7.23). On the contrary, a more consistent pattern of comparable tin additions was noted for the Epirotic (n=52), Thessalian (n= 28), and Helladic (n=14) fibulae which are all attributed to central and northern Greek workshops, which average tin values of around 9% Sn, while the middle 50% of the values typically falls between 7% and 11% tin (Figure 7.23, Figure 7.27). Fibulae of Near Eastern origin have been represented in the sample with a single Phrygian fibula for which a 9% tin bronze was used as well. Finally, the group of non-diagnostic fibulae provided a mean value for tin of 6.5% with a wide variation in its distribution from no tin added up to 13% tin which was expected for this typologically diverse group (Figure 7.22a).

Figure 7.25. Simple sheet bow fibula M 775 made of unalloyed copper

Lead content

Average lead values for all fibulae, including the group of non-diagnostic ones, were consistently found below 4% lead, suggesting that lead is mostly present as an impurity, whereas very few Thessalian and Epirotic fibulae provided evidence to support the intentional addition of lead (see also below). Nonetheless, even within the above pattern certain disparities were noted amongst the different typologies. Even though the majority of the fibulae groups showed median lead values of <1% Pb, the

Epirotic group was on average richer in lead by an average of 2%, and with mean and median lead values of approximately 3%. Nonetheless, despite these higher values, lead concentrations in the Epirotic fibulae should be taken as an impurity due to its left-skewed, long-tailed distribution which is characteristic of accidental additions of certain elements in copper, as well as the measured over-estimation of the lead values with the pXRF (Figure 7.28). In addition, EPMA analyses of lead for the Epirotic fibulae did not produce values above 3%, which further reinforces the existence of a distinct compositional pattern for this artefact group (Figure 7.26). Thus, the above pattern could suggest the systematic use of lead-rich copper from a different source for the Epirotic fibulae than the copper used for the Thessalian or Helladic types.

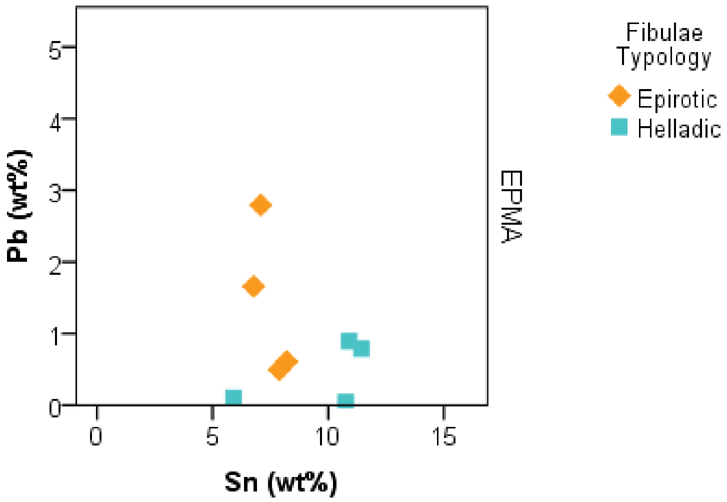


Figure 7.26. Scatterplot of tin against lead for the diagnostic fibulae analysed with the EPMA (n=8)

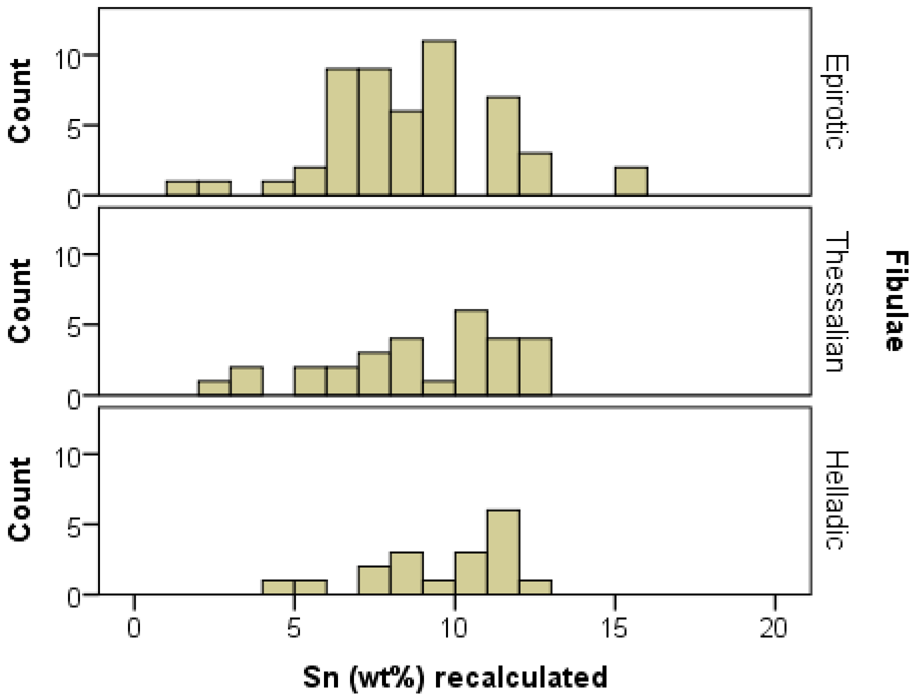


Figure 7.27. Histograms for the tin content (recalculated and renormalised after lead was removed from the totals) in the fibulae according to their typology (Epirotic, Thessalian, and Helladic fibulae)

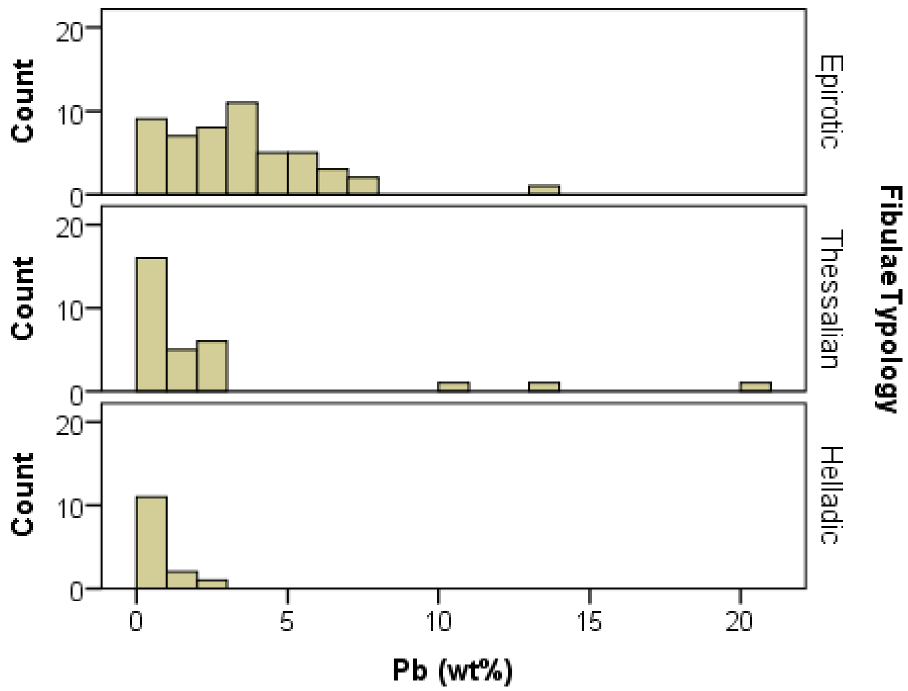


Figure 7.28. Histograms for the lead content in the fibulae according to their typology (Epirotic, Thessalian, and Helladic fibulae)

7.3.1.2 Leaded fibulae

Amongst the analysed fibulae, few outliers showed lead concentrations to suggest deliberate additions between 10% and 20% Pb. Additionally to the compositional differences, these fibulae also have distinct macroscopic features. Thus, three of them are significantly oversized, namely the Thessalian fibulae M 226.1 and M 1666.1 with lead contents 20% and 14% respectively (Figure 7.29a & b), and fibula M 282 with 10% lead and a catch-plate measuring 12 cm wide (Figure 7.29c). Even though it is difficult to classify fibula M 282 only from its catch-plate to either the Thessalian or Epirotic groups, it is tempting to assign it to the former tradition due to its composition and also due to the absence of oversized Epirotic fibulae in the entire excavated assemblage. In addition, the size of the catch-plate M 282 proportionately matches that of the oversized Thessalian fibulae.

These over-sized Thessalian fibulae with a 10 cm bow decorated with massive cast globules, a catch-plate of 12 cm long, and originally weight of approximately 400 gr would have been practically impossible to have fulfilled their primary purpose, namely to be worn as dress ornaments, one on each shoulder to support the clothing. Consequently, it is most probable that these massive fibulae were originally produced for decorative purposes and to be directly deposited as offerings to the sanctuary of Enodia. It is not hard to imagine, on the one hand, the large demand for bronze votive offerings and the offer that supplied the market not with yet another dress ornament but with an object of extraordinary dimensions; most probably with a greater value too due to its scarcity. Overall, the above results point to the artefacts' intended use as a decisive factor for the alloying choices during their production that would have increased their fluidity and castability, even though they belong to the same typological tradition, as they also raise further issues of object value.

Figure 7.29. Leaded fibulae in the sample: (A) Thessalian fibula M 226.1, (B) Thessalian fibula M 1666.1 (Kilian, 1975, D IIIq, pl. 24), (C) Thessalian or Epirotic fibula M 282 (Kilian, 1075, A-K, pl. 60, no. 1803) and (D) Epirotic fibula M 1734.3

Finally, the fourth leaded fibula M 1734.3 of the Epirotic type (Figure 7.29d), with 13% Pb and a 5 cm wide bow is interestingly of dimensions that do not differentiate it from the rest of the fibulae in the group, and its size would have not interfered with its everyday use as a dress-ornament. Since the fibula presents no other typological evidence that would suggest its manufacturing by a distinct workshop and also considering that it is a single find in the analysed sample, it is regarded as an outlier. Its high lead content does not match the pattern of lead impurity levels, but it could have still resulted accidentally if scrap leaded bronze was used for its production.

To conclude, chemical compositions of the fibulae on the whole seem to reflect the respective typological groupings too, as fibulae attributed to different regional workshops have also provided consistent chemical compositions. For all the Greek fibulae types, namely the Epirotic, Thessalian and Helladic types, a similar alloying pattern to produce binary tin bronze emerged, whereas the possibility of distinct lead-rich copper ores used in northern Greece is noted. Furthermore, the sheet bow and spectacle fibulae which showed the lowest and highest average tin values respectively in the sample have a suggested origin outside the central or northern mainland Greece, with suggested origin in Italy and the Balkans (Blinkenberg 1926, Kilian 1975). Finally, the dispersion of the compositions for the undiagnostic fibulae which was expected for such a typologically diverse group further supports by contrast the existence of particular technological choices for the different regional workshops.

7.3.2 Rings

The rings, as with the fibulae, are present in thousands in the assemblage and have been also well represented in the sample with 63 rings and spirals (Table 3.1). Under this group of objects several different ring types can be distinguished on the basis of their shape, size, and decoration. Certain ring types would have been worn as finger rings or as hair-attachments, whereas others would have been used as decorative ornaments, pendants, or even to form decorative chains as seen in Figure 7.31 where rings of different types have been combined regardless of their typology. For the purposes of this study, the sampled rings' typology has been defined by categorisation into 5 main types, i.e. I to V, on the basis of their diameter, the shape and thickness of their cross-section and their decoration where applicable. Often subtypes 'a' and 'b' have been further identified in order to account for small variations within a certain type (Figure 7.30) (for more details see Appendix I). This typological classification allowed for the morphological features of the rings to be investigated in relation to their technical characteristics such as their chemical composition and metalworking treatments.

Table 7.4. Summary table for the (A) tin and (B) lead contents in the ring group according to subcategories

Ring type	**Ia**	**Ib**	**IIa**	**IIb**	**III**	**IVa**	**IVb**	**Va**	**Vb**
N	23	2	5	4	8	11	3	6	1
A					**Sn (wt%)**				
Mean	8.2	9.5	7.5	11.2	8.7	8.7	5.0	8.6	17.7
Median	6.9	9.5	8.1	12.7	10.1	10.1	4.6	8.1	17.7
Min	2.5	9.2	3.0	6.4	0.5	1.5	4.5	7.3	17.7
Max	14.8	9.8	11.2	13.1	11.3	12.3	6.0	11.5	17.7
Range	12.4	0.6	8.2	6.7	10.7	10.7	1.4	4.2	0.0
B					**Pb (wt%)**				
Mean	4.2	0.0	3.6	4.1	0.7	4.3	8.1	0.2	0.6
Median	0.3	0.0	0.6	3.8	0.1	4.0	8.5	0.2	0.6
Min	0.0	0.0	0.2	1.1	0.0	0.0	2.0	0.0	0.6
Max	26.5	0.0	14.6	7.7	4.3	11.3	13.7	0.5	0.6
Range	26.5	0.0	14.5	6.6	4.3	11.3	11.7	0.5	0.0

The largest ring categories both in the recovered assemblage and the analysed sample are the simple, wire ring with round cross-section of around 2 mm thickness and a diameter of approximately 2 cm (Type Ia, 23 samples), large cast rings with thick round cross-sections and a diameter of up to 4 cm

(Type IVa, 11 samples), and rings formed of folded thin metal sheet with incised or embossed decoration (Type III, 8 samples) (Figure 7.32). Quantitative results for the major elements presented below include analyses of both the EPMA (35 samples) and pXRF (28 samples). Invasive sampling of a several rings took place due to their often fragmentary state and open ends, e.g. ring AE 506 (Figure 7.36). Conversely, whole rings such as rings AE 26 and AE 109 have been analysed non-invasively with the pXRF (Figure 7.32a & c).

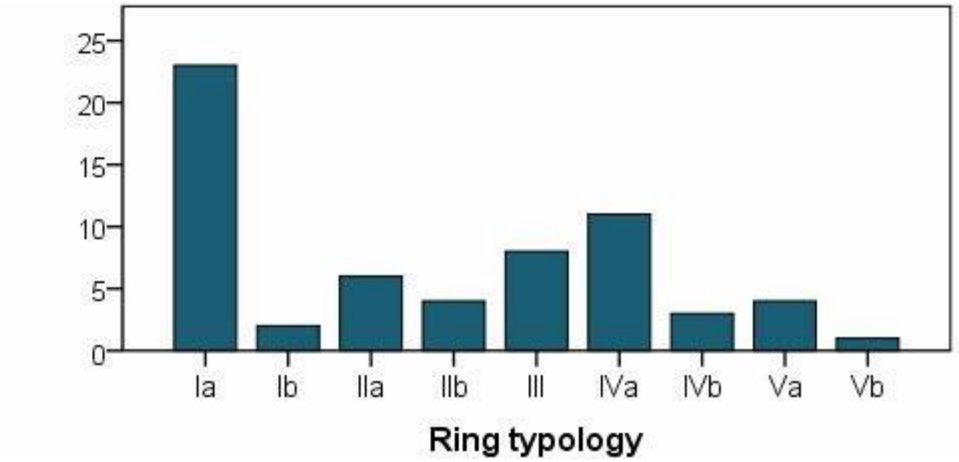


Figure 7.30. Barchart showing the different ring types present in the sample as they have been defined for the purposes of this study

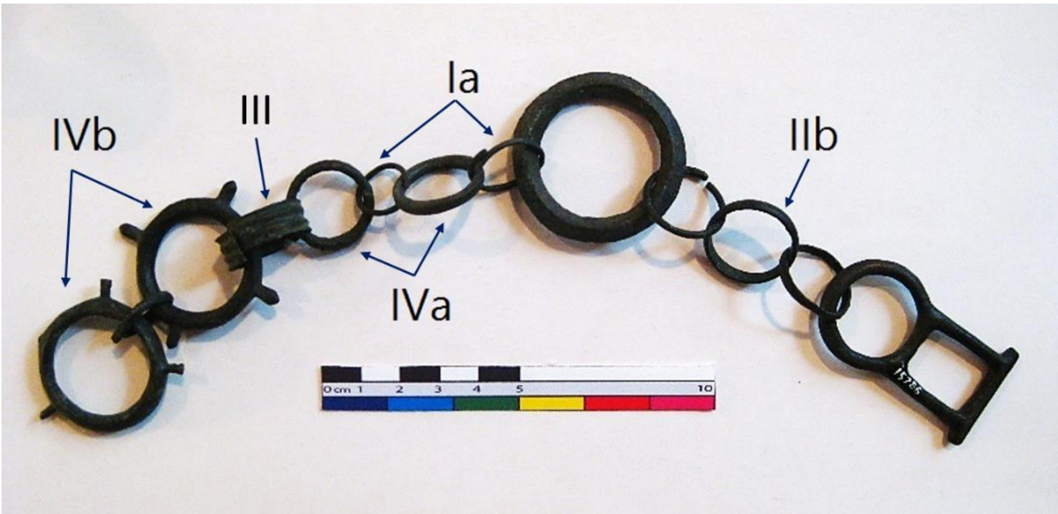


Figure 7.31. Chain formed from different types of rings recovered at the sanctuary of Pherae; ring typology indicated as established during the present study (NAM, no. 15786)

7.3.2.1 Compositional characteristics

The variation noted in the rings typology was overall reflected in their compositions too with a wide spread of values for both tin and lead which range widely between levels of naturally occurring impurities up to 17% for the tin and 26% for the lead contents (Figure 7.33). In addition, pXRF results included more lead-rich rings as opposed to the EPMA dataset, a pattern similar to this of the fibulae analyses (Figure 7.34). Meanwhile, even after moderation of the lead content for the pXRF by -30% as suggested by analyses of CRMs, certain rings still appear to have been deliberately leaded.

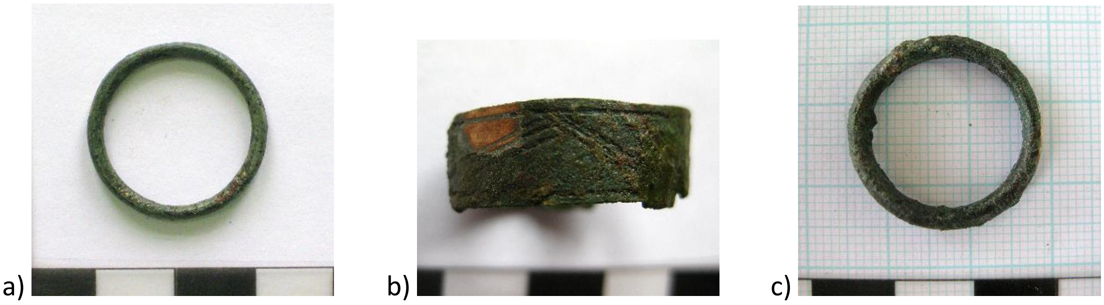


Figure 7.32. (A) Type Ia (AE 26), Type III (AE 118) and Type IVa (AE 109) which are most frequently found in the sample

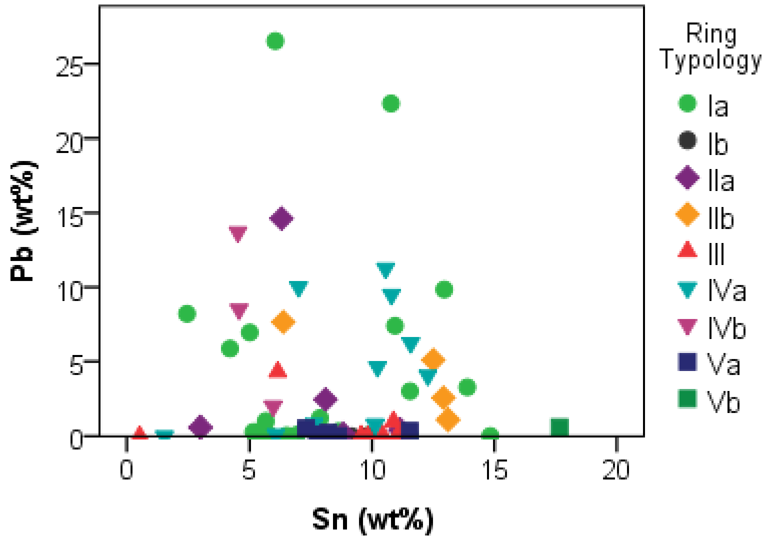


Figure 7.33. Scatterplot of tin against lead for the rings according to ring typology

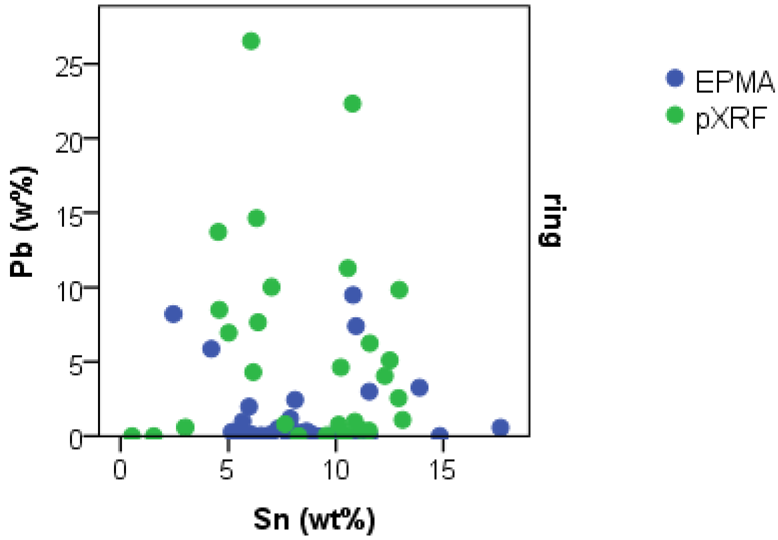


Figure 7.34. Scatterplot of tin against lead for the rings in the sample according to analytical technique

The rings' bulk composition resembled that of the entire sample with few unalloyed copper and leaded bronze rings, while the vast majority consists of binary bronze with variable tin contents. Even though no direct correlation between the rings' composition and typology was visible as binary or leaded bronze alloys seem to have been invariably used, different degrees of variation and patterns emerged across the different ring types and subtypes. Hence, rather dispersed values were seen in types I and IV, as opposed to more clustered ones for types III and V (Table 7.4, Figure 7.35). Below, the different ring typologies are discussed in conjunction with their chemical compositions in order to reveal further such patterns.

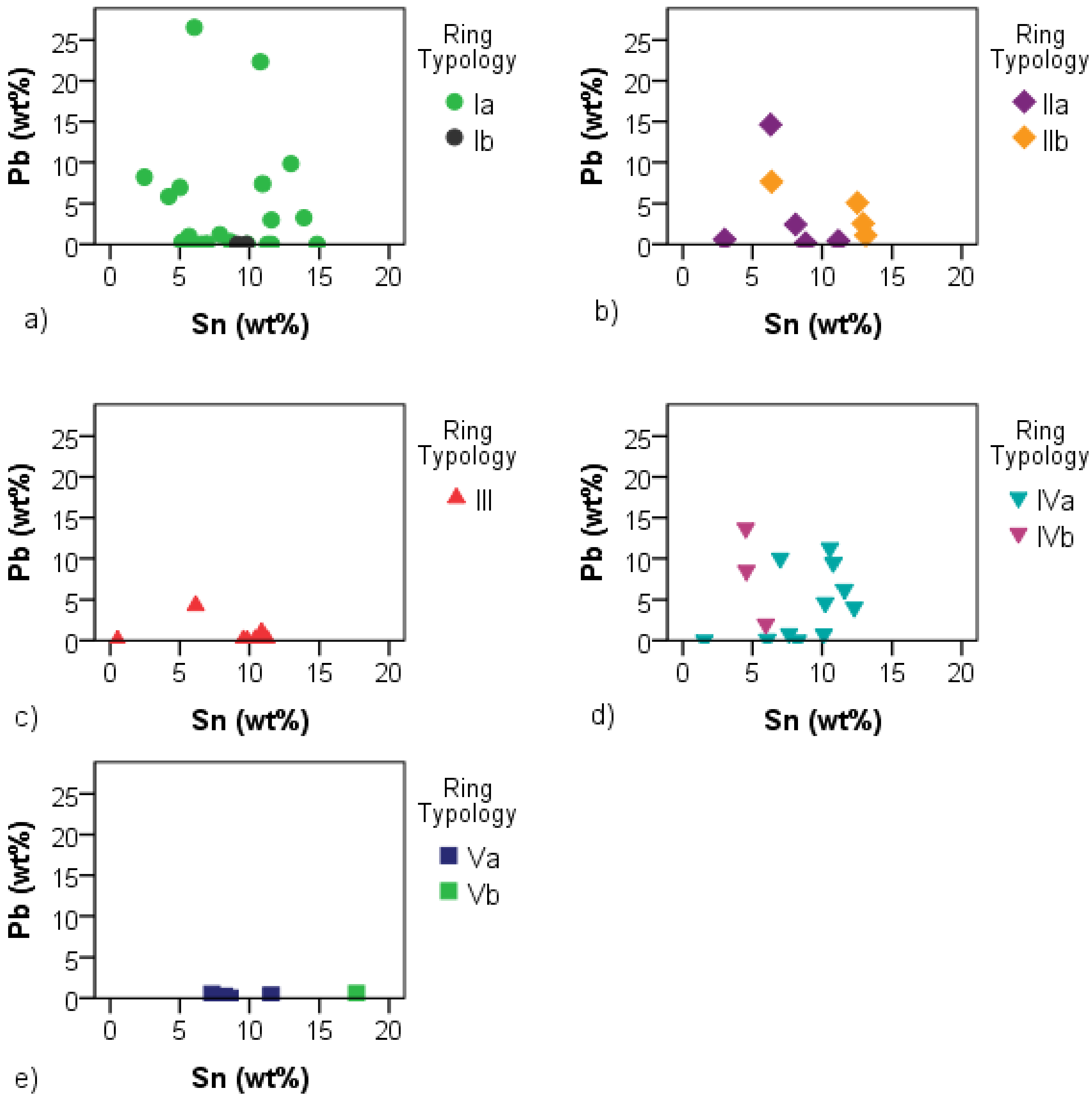


Figure 7.35. Scatterplots of tin against lead for the different ring types present in the sample

Type I

Type Ia rings which is the group represented with the most objects in the sample (23 rings) showed the greatest variation in both the tin and lead contents with ranges of 12% and 26% respectively. In this group also belong the two most lead-rich rings in the entire sample, namely AE 765 and AE 26, with values of 22% and 26% lead respectively. Even if the aforementioned lead values are moderated by -30%, they would give values of 15-18% Pb, and they would still point to these two rings being particularly lead-rich. This is of interest given that their typology is identical to the rest of the Type Ia rings which are typically characterised by moderate tin and lead contents of 8% and 4% respectively. The variation in the bulk compositions for this group could be justified by the simple form and small size of the rings with absence of any characteristic decoration which could have been produced by any copper-based wire if folded round. Consequently, production of the above rings would not have necessarily required any particular or advance metalworking knowledge and a number of smiths and metalworkers could have manufactured them. Finally, the two rings of Type Ib which form a variation of Type Ia decorated with characteristic spiral endings (see Appendix I, Figure I.3) provided similar compositions of a 9-10% binary tin bronze (Figure 7.32a) possibly pointing to a common sources for their production.

Types II & IV

Ring Types II and IV present some common compositional features as they consist on the whole of tin bronze with variable lead contents with mean tin values of 9% and 8% for types II and IV respectively, and mean lead contents of 4% and 5% and even lower median values of 2% and 4% Pb respectively. Furthermore, for the subtypes 'a' and 'b' of ring Types II and IV characteristic compositional patterns of distinct clusters emerged. Subdivision of Type II took place on the basis of the rings cross-section (IIa: triangular, IIb: plano-convex cross-section), while Type IV rings were subdivided according to the presence or not of decorative projections (usually four or five) (see also Appendix I). Thus, rings of subtype IIb typically cluster around a 13% tin bronze, while IVb rings cluster around a low tin bronze of approximately 5-6% tin and with variable amounts of lead (Figure 7.35b & d). Even though few rings are present in both subtypes, the above described compositional clusters point to certain control being exercised over the different rings' manufacturing.

Figure 7.36. Lead-rich ring AE 506 (Type IVa) with 9% as analysed with EPMA

Types III & V

In contrast to the rest of the ring types, ring Types III and Va showed the tightest clustering of tin and lead values (Figure 7.35c & e). Both these types are of binary bronze and are exclusively lead-free. Both ring types have mean tin values of around 9% Sn, while a tendency for higher tin contents in Type III was noted in the median values of 10% as opposed to 8% for Types Va (Table 7.4).

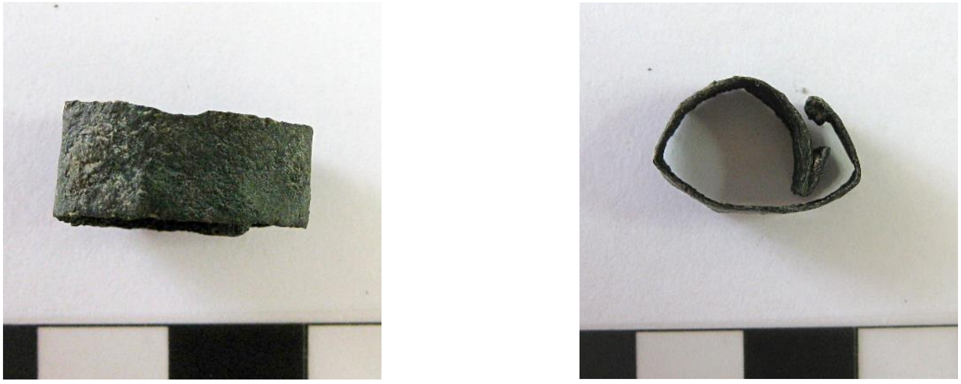


Figure 7.37. Unalloyed copper Type III ring AE 900

In addition to the above general pattern, certain outliers amongst the aforementioned ring types are visible including the rings AE 900 and AE 118, and the spiral 899. Thus, ring AE 118 consists of low-tin bronze with a significantly lower tin content by the vast majority of the rings in the group, i.e. 6% tin (Figure 7.32b), while it is also the only ring in the group whose pXRF analysis showed traces of lead of 4% Pb (or 3% Pb if this value is moderated by -30%). Even though such low lead content is not sufficient to classify the object as deliberately leaded, it does however differentiate it further from the rest of the rings in this group whose lead content does not exceed 1% Pb. In addition, ring AE 900 is not only the only ring of unalloyed copper amongst the rest of its group, but it also typologically different. The copper ring is formed from a simple metal sheet with no incisions on its outer surface, as for the rest Type III rings, while it is formed with a variable width and the endings of the folded sheet seem not to have been joint with great care (Figure 7.37). The above characteristics point to a cruder manufacturing of an established ring type which is produced by a cheaper alloy too.

Finally, spiral AE 899 (Type Vb, Figure 7.38) stands out due to its exceptionally high tin content. The spiral with a tin content of 18% distinguishes itself not only from the rest of the spiral rings which typically do not contain more than 12% tin, but also from the entire sample where very few analysed objects produced tin values of >15% (Figure 7.33 & 7.35e). As also seen for the copper ring AE 900, the typology of the spiral is different from the rest of the spirals in the group as it consists of a significantly smaller diameter from Type Va. This spiral with its minute diameter would have been impossible to wear as a finger ring and was probably used for hair decoration (Figure 7.38). Its high tin alloy would have originally appeared with a particularly silvery tint.

Figure 7.38. Tin-rich spiral ring AE 899 (Type Vb) probably used to decorate hair

Overall, by looking at the different groups and sub-groups of the rings in the sample it becomes apparent that the more typologically distinct the ring groups are, the better clustered values for the major elements are visible. Examples of such variations in the typology of the rings which are reflected on chemical compositions of the respective groups are seen in all ring Types examined here.

7.3.2.2 Rings' metalworking

The metalworking techniques identified amongst the group of rings, as with the quantitative results, are varied and closely match the observations for the entire sample discussed above. Thus, hammered and annealed rings dominate (22 rings, C/D), whereas fewer examples with traces of mild metalworking (10 rings, B) or as-cast structures were found (3 rings, A). Nonetheless, for certain ring types a preference for laborious metalworking was noted and even though there are few subtypes that consist of rings with traces of variable metalworking intensities (Types Ia, IVa, and Va), there are other that consist only of repeatedly hammered and annealed rings (Figure 7.39).

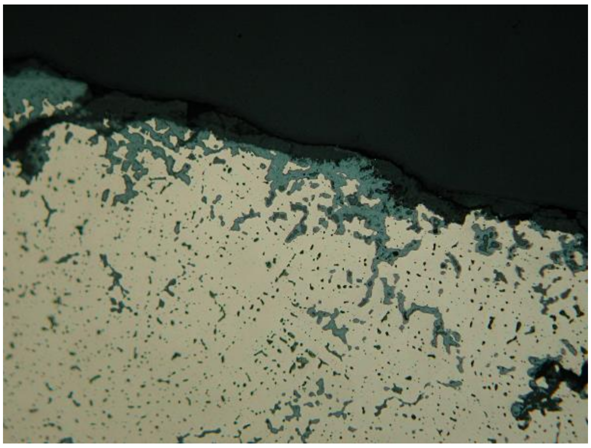
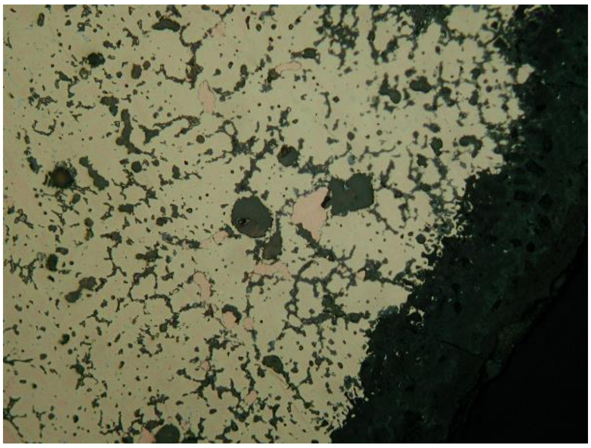



Figure 7.39. Photomicrographs of rings 1310 and AE 507 where an as-cast structure with dendrites throughout the sample's cross-section is visible; PPL, 500x, image width 350 μm

Cast rings all belonged to Type Ia and they include three out of the four objects in the entire sample with evidence of solely as-cast structures. Type Ia rings which have provided quite variable chemical compositions too, also consist of the simplest ring type in the sample, and, thus cast structures found amongst objects of this group are not surprising considering that no particular working of the copper-alloys would have been needed in order to shape these thin wire rings. The cast rings bulk compositions have a rather wide range of alloys and rings AE 507 and AE 654 consist of a 14% and 10% tin bronze respectively, whereas the ring 1310 of a leaded bronze with low tin content of 2% tin and 8% lead (Figure 7.39).

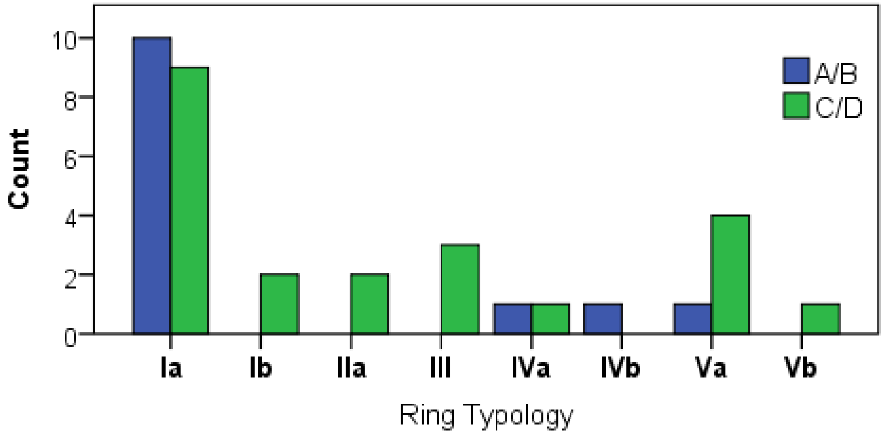


Figure 7.40. Barchart of the different ring types in the EPMA sample according to the metalworking techniques as seen in the rings' sections (n=35)

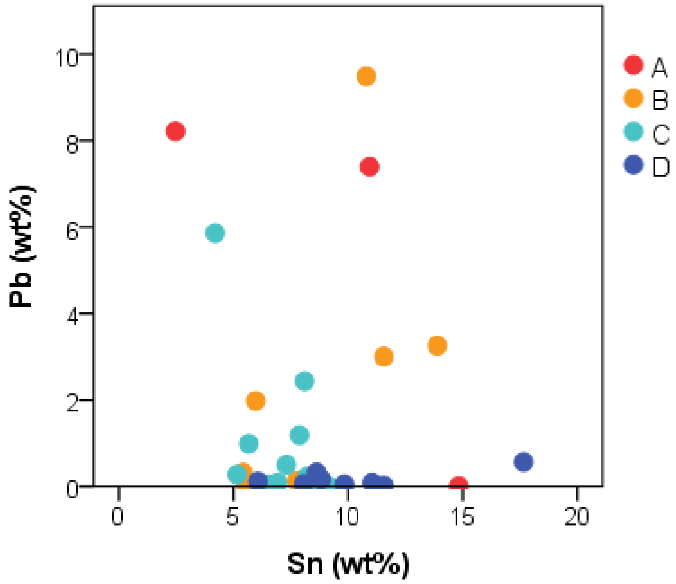


Figure 7.41. Scatterplot of tin against lead for the rings according to metalworking technique

Finally, a pattern for the intensively worked (D) rings to be typically lead-free and richer in tin with a mean value of 10.3% tin was noted (Figure 7.41). Meanwhile, average tin content for the rest of the metalworking groups drops in correlation with the metalworking intensity as the worked (C), slightly worked (B), and as-cast (A) rings showed mean values of 9.4%, 8.5% and 7.5% respectively. On the contrary, the lead content is more variable, as all A, B, and C metalworking groups include one or two rings which contain lead between 6% and 9% Pb.

7.3.3 Metal sheets and bands

Twenty-three pieces formed from thin metal sheets have been included in the sample. Pieces of metal of 1-3 mm thickness have been subdivided in metal sheets (20 samples) and bands (3 samples); the former are fragments from a variety of larger objects such as vessels, helmets, or other decorative objects (Figure 7.42a), while the latter are long sheets of metal with a consistent width of approximately 2 cm and thickness of 2 mm, and often have incised decoration on one of their sides as, for example, band M 4418.2.2 (Figure 7.42b). These are discussed here together since they would have both been manufactured by applying similar metalworking techniques such as repeated hammering and annealing in order to form such thin metal pieces. Furthermore, within this group, four fragments most probably from vessels have also been included, namely AE 66, AE 279, AE 441 and M 1844.

a)  b) 

Figure 7.42. (A) Metal sheet AE 289 and (B) metal band M 4418.2.2

Metal sheet fragments consisted largely of binary bronze, while a couple of unalloyed copper fragments were also analysed (e.g. AE 289, Figure 7.42a). The vast majority of the metal sheets (21 out of 23 samples analysed) contained only lead impurities at levels below 1%, and only a couple of samples contained higher lead amounts of 5-8% Pb (Figure 4.23). At this point it is worth noting that due to the metal sheets' fragmentary state several cut samples were possible to be obtained and, thus, 17 out of 23 samples have been analysed by EPMA. Consequently, it is not surprising that the two sheets richer in lead in comparison to the rest of the objects in the group have been both analysed with pXRF and their lead contents should be rather considered in the range of 3.5-5% Pb after moderation. Nonetheless, all four vessel fragments have provided rather comparable tin values between 7% and 9% tin.

No particular correlation was noted between the metal sheets' typology and bulk composition, as their tin content varied between 5% and 14% Sn, while their lead content was more consistent with a maximum value of 0.8% Pb. Finally, the sheets' and bands' metallographic investigation showed that different degrees of metalworking intensity were employed from mild to repeated hot- and cold-working positively correlated to the tin additions as slightly worked sheets typically contained low tin of up to 6%, whereas worked and intensively worked had tin contents of 7-10% and 8-12% respectively (Figure 7.44).

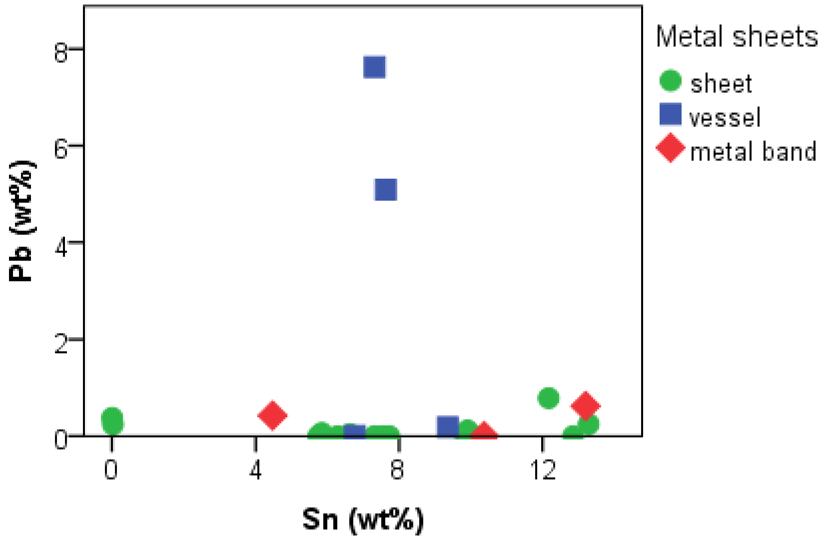


Figure 7.43. Scatterplot of tin against lead for the metal sheets in the sample (n=17) as analysed with both methodologies (13 samples with EPMA, 4 samples with pXRF)

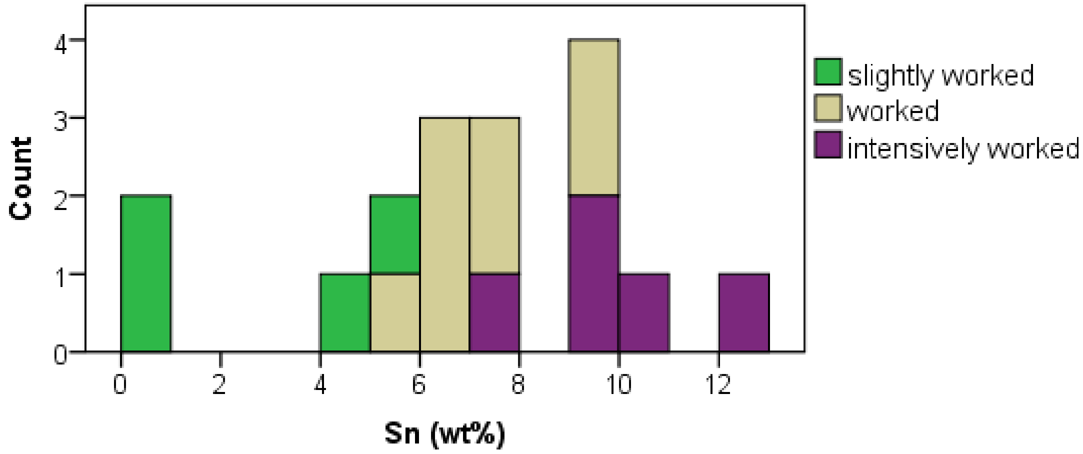


Figure 7.44. Barchart of tin distribution in the metal sheets group according to metalworking (n=17)

7.3.4 Pendants

The last artefact group discussed in its own right are the pendants which include a variety of types owing to the pendants' definition which signifies any object that is meant to be hung as a decoration element. This artefact group is formed of 33 samples and includes the quite popular bird, wheel disk and biconical pendants which are also well-represented in the entire assemblage, along with the more rarely found double-axe pendants, while few undiagnosed pendants have been also included. The bulk composition of the different pendant types showed the absence of unalloyed copper objects along with a preference for tin additions between 5% and 15% tin. Lead is typically found at impurity levels, while fewer pendants mostly belonging to the bird and biconical types are leaded with variable lead contents 5-15% Pb (Figure 7.45). Elevated lead contents for both the bird and the biconical pendants would be further justified taking into consideration that both types would have been cast, as opposed to the wheel disk or double-axe pendants which are formed from thin metal sheets.

Table 7.5. Summary table for the tin and lead values for the different pendant types

	bird (n=15)		biconical (n=5)		wheel disk (n=7)		double-axe (n=1)		other (n=5)	
	Sn	Pb	Sn	Pb	Sn	Pb	Sn	Pb	Sn	Pb
Mean	11.4	2.4	11.2	3.3	9.8	0.5	9.0	0.4	7.5	5.3
Std. Dev.	1.4	3.9	3.1	4.3	1.3	0.5	-	-	2.4	9.3

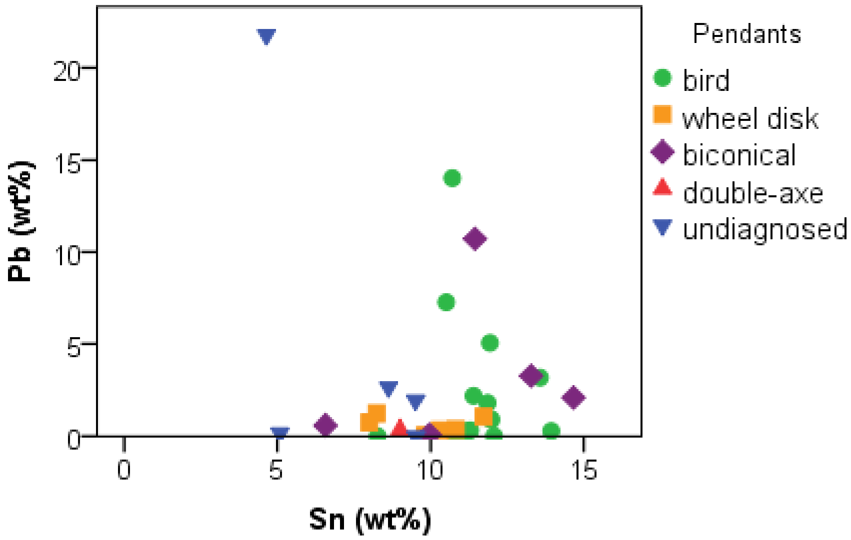


Figure 7.45. Scatterplot of tin against lead for the different types of pendants in the sample

The bird and wheel disk pendants are amongst the better clustered types compositionally with standard deviations for tin of just 1%. The tin distribution of the bird pendants, in particular, forms a bell-curve with a mode at 11% tin (Figure 7.46, Table 7.5). Amongst the different pendant types, the biconical pendants seem to have the widest distribution for both tin and lead with standard deviations of 3% and 4% respectively. Finally, the particularly lead-rich pendant M 2292 with 22% lead stands out not only compositionally, but also typologically as it was not possible to assign it to any known pendant or other type. It has been grouped here under the pendants since its use as a decorative ornament has been considered most probable. Overall, bulk compositions for the majority of the pendants in the sample seem to fall at the high end of the tin distribution spectrum with values falling mostly around 10% tin.

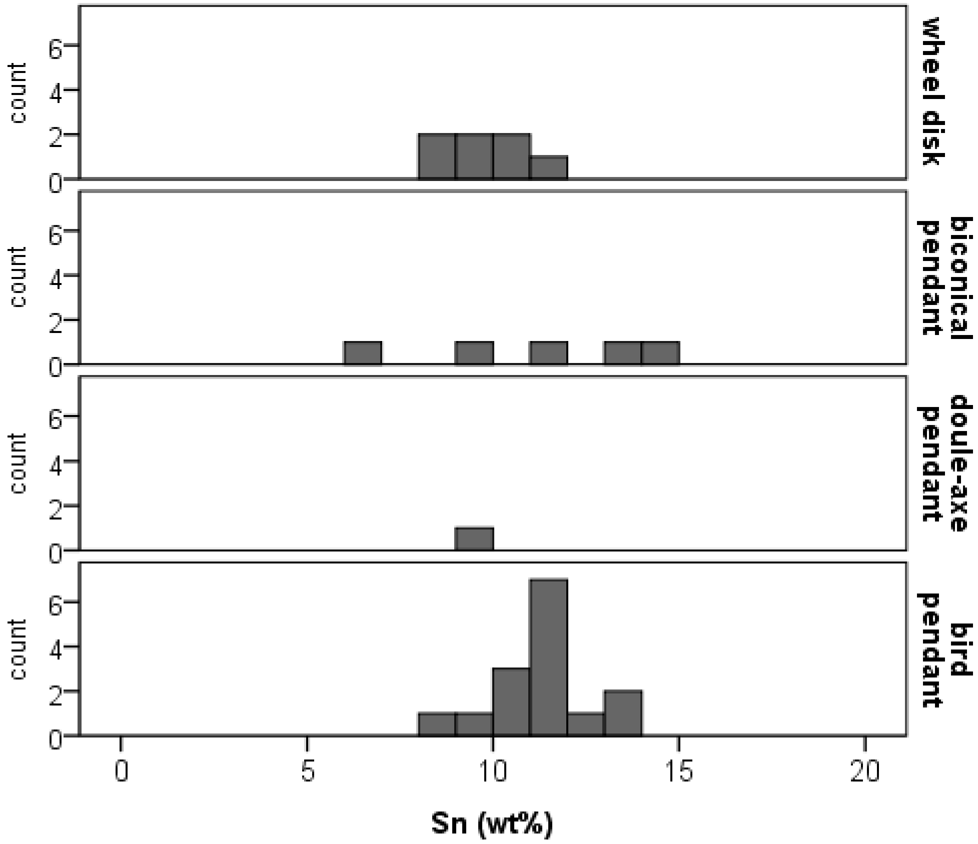


Figure 7.46. Histograms for the tin distribution in the groups of pendants in the sample

Part III

Chapter 8. Comparative discussion of Early Iron Age copper-based artefacts analyses

Quantitative results of the Pheraean assemblage have been hereby brought together with published datasets from Early Iron Age Greece including:

- the nearby sanctuary of Kalapodi as analysed by Riederer (2007) with neutron activation analysis (NAA),
- the settlement of Nichoria in Messenia analysed by Rapp et al. (1978) by X-ray fluorescence (XRF) and optical emission spectroscopy (OES),
- the tripods mostly from Delphi analysed by Rolley et al. (1983) and Marangou et al. (1986) by atomic absorption spectroscopy (AAS),
- various objects of Greek origin as analysed by Craddock in two papers published in consecutive years (1976; 1977) also by AAS,
- and, finally, a small group of objects from the Toumba cemetery at Lefkandi as analysed by the author (2009) by EPMA and scanning electron microscopy (SEM) (for a detailed overview of these publications' methodologies see Chapter 2).

The XRF analyses of 111 objects from the cemeteries of Lefkandi by Jones (1980) and 18 objects from several sites including the Argolid, Olympia, Samos, and Ithaca by Davies (1934) by means of spectroscopy have not been included due to their overall low analytical totals resulting from the presence of corrosion products. Even though the above analyses proved the objects' copper-based character, it would not promote the comparative discussion of Early Iron Age copper-based production below. All results discussed have been normalised to 100%.

For the datasets listed above, the use of different analytical instruments used with variable minimum detection limits, and accuracy and precision levels posed certain limitations which have been addressed by putting emphasis on the bulk compositions and major elements, namely copper, tin and lead, and patterns emerging within the individual assemblages, rather than on the trace elements. Furthermore, pXRF lead values for the Pheraean sample have been moderated to 70% of their original analysed values as suggested by comparison with the CRMs (with the pXRF) and the EPMA results (see also Chapter 3, Figures 3.15 & 3.22), whereas the tin concentrations have been presented as analysed. Finally, in the consideration of the trace elements only the EPMA dataset has been included (as in Chapters 5-7).

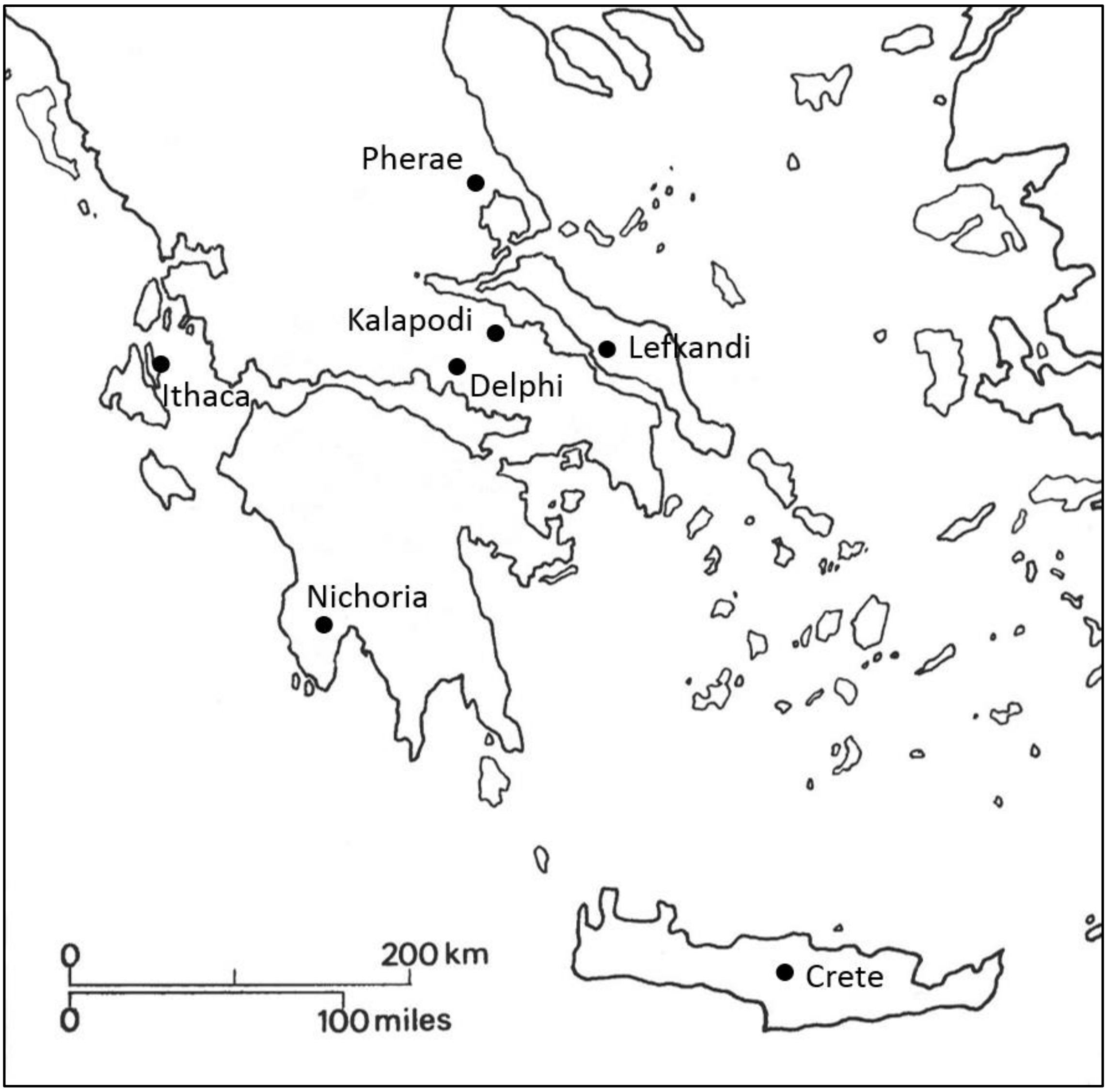


Figure 8.1. Map of central and southern Greece with the main sites mentioned in the chapter

8.1 The sanctuaries: Pherae, Kalapodi, and Delphi

The sanctuaries at Pherae, Kalapodi and Delphi share certain characteristics not only regarding their use, but also the nature of the copper-based objects votive offerings deposited. As sanctuaries they were fulfilling important religious functions but also a range of broader, dynamic and complex ones as centres of overall social interactions (see also Chapter 1.2). These locations are characterised by diachronic use, though not necessarily cultic, from the Mycenaean period onwards. Even though recent research has revealed a sequence of ten temples from approximately 1400 BC to the 2nd century BC at the oracle sanctuary of Apollo at Kalapodi in northern Phocis (Niemeier 2013), Late Bronze Age activity at Delphi can be speculated but it is still rather more obscure while the first cult dedications are dated at around 800 BC (Mazarakis Ainian 1997, pp. 311, 338). Meanwhile, excavated evidence dating to the 11th century BC has been recovered both from Delphi at the south-western slopes of Mount Parnassus in southern Phocis and the Thessalian Sanctuary at Pherae.

On the one hand, they have all hosted cults dedicated to Olympian Gods which attracted a significant proportion of available wealth as expressions of religious sentiment and public engagement, while they present a similar depositional record of copper-based votive offerings which accumulated gradually with a peak of this activity in the 8th and 7th centuries BC. These votive assemblages, even though not identical, they do present some similarities such as in the fibulae, horse figurines, or the bird, and wheel disk pendants dedicated. In addition, all three sanctuaries are geographically associated in central mainland Greece (Figure 8.1) even though Thessaly would be best put close to the northern border of ancient Greece. The latter is, for example, seen in the Early Iron Age sanctuary distribution (Figure 8.2) which would justify more pronounced cultural ties with Macedonia as seen in the group of Macedonian bronzes recovered (see Appendix I, Figure I.28 & 29) and also the spread of the Enodia cult itself (Figure 8.3). Finally and most importantly for the present investigation, scientific analyses of their record of copper-based artefacts dating to the Early Iron Age has been conducted from the 1980s onwards.

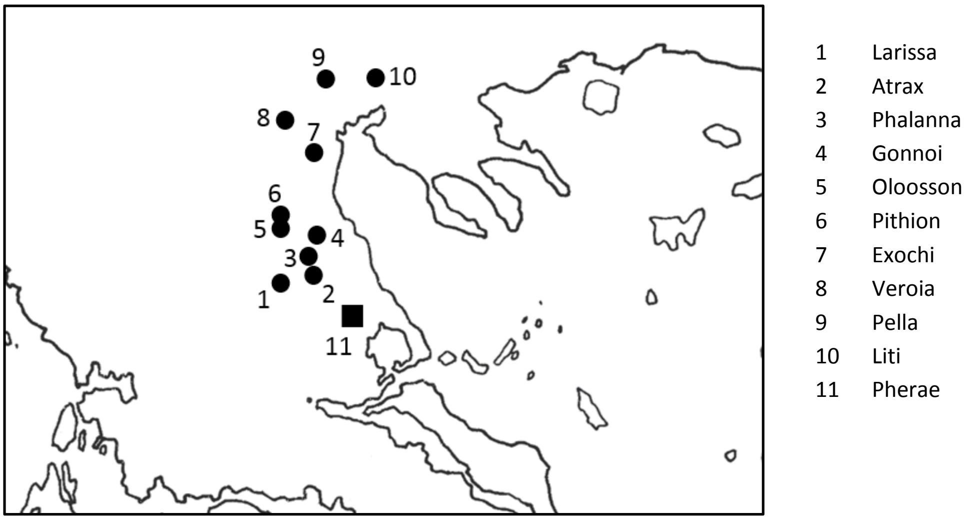
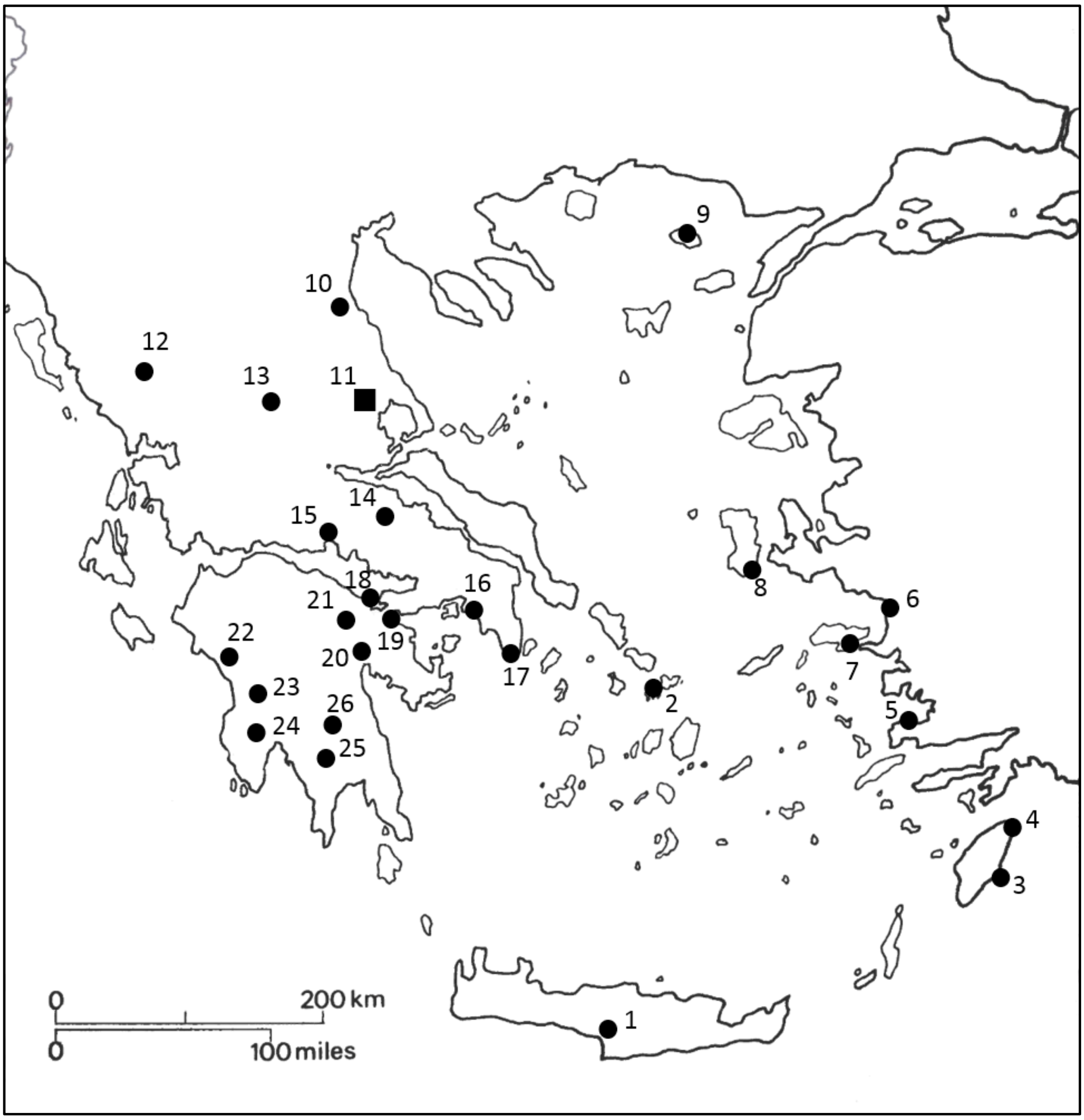


Figure 8.2. Map of northern Greece with sites where cults of Enodia have been recovered

On the other hand, these sanctuaries played particular roles within their attached communities as they enjoyed different degrees of external control via local or otherwise political entities. The Delphi oracle dedicated to Apollo was admittedly the most renowned as it attracted pilgrims from all over Greece and as illustrated by its characterisation as the *'centre of the world'* (=omphalos) from the 8th century onwards, while it also enjoyed certain degree of self-management. However, the Pheraean sanctuary dedicated to the national Thessalian goddess Enodia must have played a prominent role amongst the communities of Thessaly and its surroundings, but it would not have had the same international pilgrimage as with Delphi. Even though it attracted imported dedications from travellers and passers-by due to its position on the cross-roads between north and central Greece, the cult of the local Thessalian patron further emphasised the sanctuary’s strong ideological ties with the local communities.



1	Idaean Cave	10	Dion	19	Isthmia
2	Delos	11	Pherae	20	Argos
3	Lindos	12	Dodona	21	Nemea
4	Rhodes – Helios	13	Philia	22	Olympia
5	Halicarnassus	14	Kalapodi	23	Bassae
6	Ephesus	15	Delphi	24	Messene
7	Samos - Heraion	16	Athens – Parthenon	25	Sparta – Artemis Orthia
8	Chios – Emporio	17	Sounion	26	Tegea
9	Samothrace	18	Perachora		

Figure 8.3. Map of the Iron Age sanctuaries in Greece and the Aegean

Furthermore, the close proximity of the Enodia sanctuary to the actual site of Pherae (>1 km), along with its rather limited size and facilities both point to the control that settlement had on the sanctuary's administration. Thessalian society overall followed a rather different path from the ones of central and southern Greece where many settlements developed into city-states with variable degrees of self-sufficiency and self-management of their internal affairs. Thessaly rather formed a larger political entity with different social organisation and more pronounced national ties between its communities, namely the Thessalian ethnos (Morgan 2003, 2006). The above is reflected not only in the dedication of the Pheraean sanctuary to the Thessalian patron deity Enodia, but also on the circumstances that paved the way for the birth of such a national deity in the first place.

The above account of the similarities and discrepancies between the three sanctuaries, aimed at a concise overview of their particular social roles as these potentially had an impact on the way technological workshops operated including the organisation of labour, supply of raw materials and know-how, and/or the distribution of finished objects. Meanwhile, a more detailed discussion is beyond the scope of the present discussion which focuses more on the technological aspects of the copper-based votive offerings.

8.1.1 Comparative analyses from the sanctuaries

Results from Pherae, Kalapodi and Delphi are discussed below in order to reveal possible patterns for the copper-based production in relation to the sanctuaries of central mainland Greece. Prior to the actual presentation of results, it is worth noting that only the tripods have been analysed from Delphi as dictated by the archaeological question posed by the researchers in the first instance (see Chapter 2.4.1), while a wide range of copper-based artefacts from Pherae and Kalapodi has been investigated in the respective samples.

Even though linking these assemblages with their actual production sites is challenging given the available evidence, the rather local character of the majority of the assemblages is adopted here, albeit with no strict geographical boundaries. Thus, the majority of the offerings recovered from the sanctuary of Enodia have been assigned to a Thessalian production, while material from Delphi and Kalapodi would be most likely attributed to a central Greek metallurgical tradition. Despite the presence of non-local objects such as the Epirotic fibulae in the Pheraean sample, these would not have particularly affected the overall results to a dramatic extent and, thus, the entire analysed samples have presented below.

8.1.1.1 Alloy recipes

In outlining the various alloy recipes, namely unalloyed copper, binary bronze and leaded bronze, the same characteristics as for the Pheraean sample have been adopted (see Chapter 4). Even though the sanctuary datasets have been the result of different analytical techniques, the above border lines for the tin and lead additions provided some common grounds for the comparison of the three datasets.

On the whole, a similar range of copper-based alloys is present in all three assemblages as both unalloyed copper and binary copper-tin and/or leaded alloys have been identified (Figure 8.4). The predominance of alloys as opposed to unalloyed copper or of lead-rich objects was commonly found. In the tin additions a marked decrease in the amounts larger than 15% Sn was found across the datasets. Hence, no tripods were found with tin concentrations larger than 14.6% Sn, while just a handful of samples from Pherae and Kalapodi consisted of binary bronze with tin contents between 15% and 21%. Meanwhile, objects with >20% tin included the possibly imported bead from Pherae and a 'workshop residue' sample from Kalapodi (B 1971) which points rather to the production of tin bronze *in situ* (see also discussion for Nichoria below, Chapter 8.2).

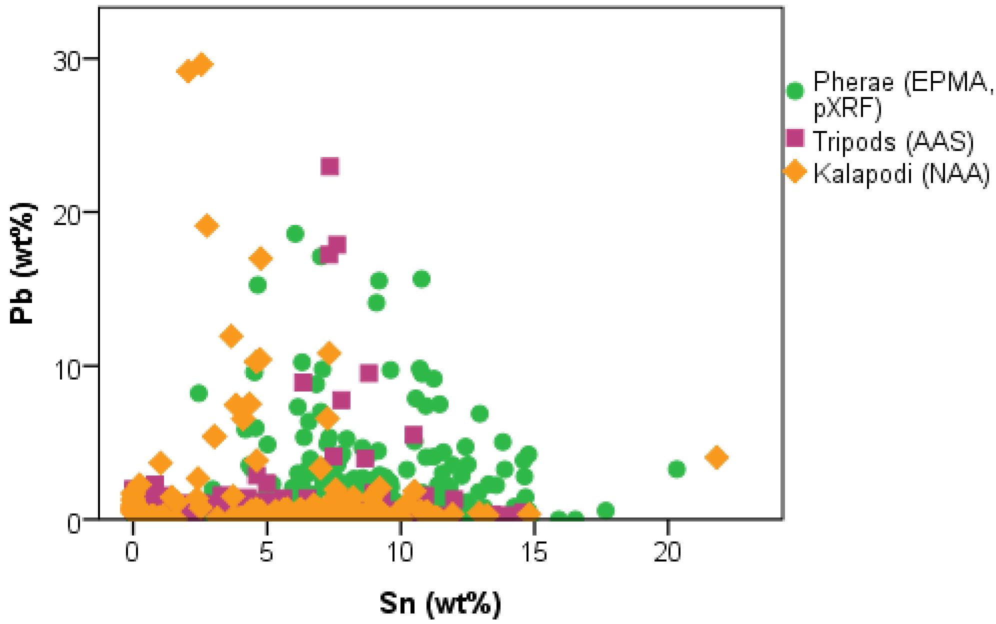


Figure 8.4. Scatterplot of tin against lead for the analyses from Pherae, Kalapodi (after Riederer, 2007) and the tripods from Delphi (after Rolley et al., 1983; Marangou et al. 1986)

For Pherae and Kalapodi the vast majority of the samples analysed consisted of tin bronze with 79% and 68% of analysed samples respectively, whereas the equivalent percentage for the tripods is only 46% (Table 8.1). Furthermore, even though in Pherae leaded bronze covers 15% of the sample, this is rather under-represented in central Greece with 10% and 7% of the Kalapodi and tripod datasets respectively. Despite that unalloyed copper is more prominent in the Kalapodi and tripods analyses, it is disproportionately represented in the two datasets with only 22% for the Kalapodi sample, while it consists almost half of the assemblage from Delphi analysed with 47% of the sample being of unalloyed copper. Similar amounts of samples of unalloyed copper (47%) and alloys (53%, including both binary and lead bronze) and the relative absence of leaded alloys seen in the tripods, could be related to the nature of this particular artefact type itself as most of the different parts of the tripods, with some exceptions such as these of the griffin attachments, would have been hammered into shape rendering, thus, lead an unwelcome addition. Finally, both Pherae and Kalapodi samples showed few leaded objects with tin contents smaller than 4% Sn, whereas leaded tripods were only seen around a 8-10% tin bronze (Figure 8.5). Finally, Kalapodi showed an overall tendency for low-tin leaded bronze in comparison to Pherae.

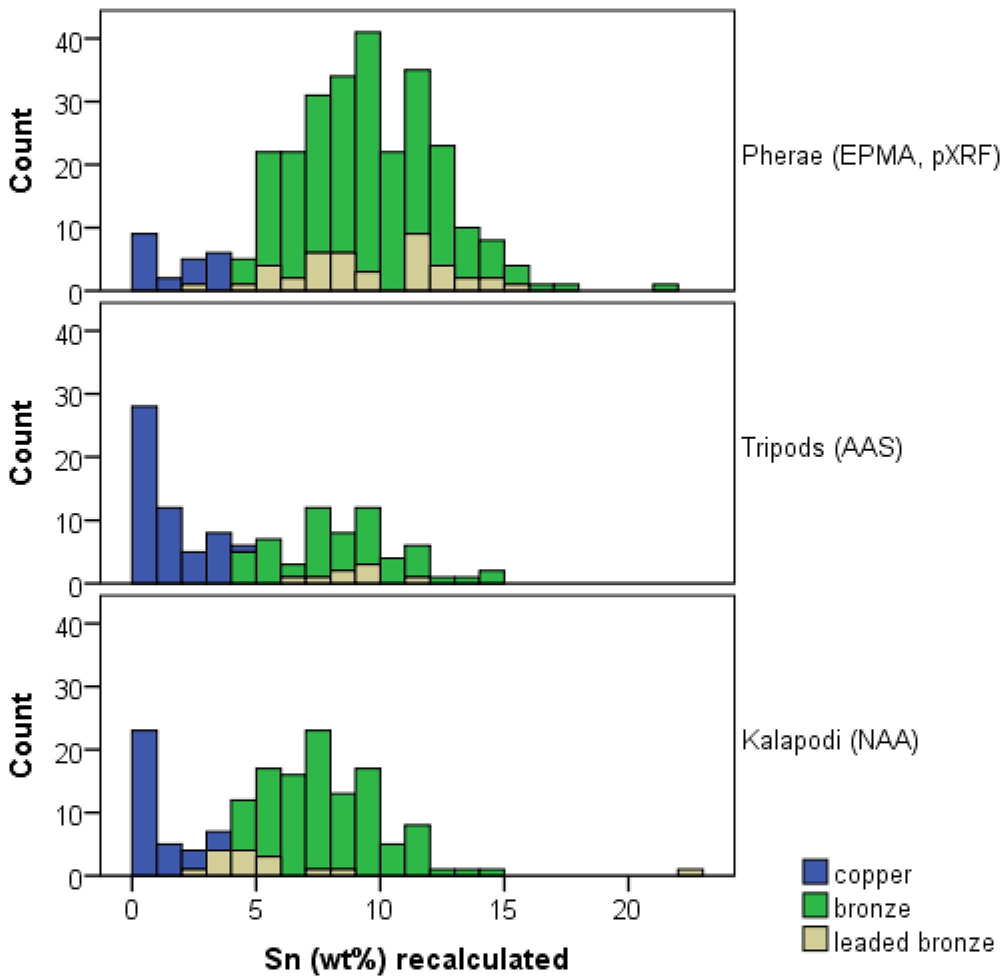


Figure 8.5. Histograms of tin content recalculated after the lead was taken out of the totals in the assemblages of Pherae, Kalapodi, and the tripods from Delphi

8.1.1.2 Tin and lead addition modes

Despite that binary and leaded bronze objects are present in all sanctuary datasets, investigation revealed certain disparities in the modes of addition for tin and lead to copper. Despite that between the assemblages from Pherae and Kalapodi a general preference for binary tin bronze was evident in relation to the tripods, the actual amounts of tin added on average are quite different with mean and median values of 9% and 6% Sn respectively. On the contrary, greater uniformity was seen between Kalapodi and the tripods whose average tin amount was found at 5% Sn (Table 8.2). Furthermore, even though overall bell-curve, normal tin distributions were seen for Pherae and Kalapodi, the same cannot be said for the tripods which showed more random and spread tin values (Figure 8.5). Nonetheless, all three assemblages showed comparable mean lead values which ranged from 1.5% for the tripods to 1.9% Pb for Pherae, low median values between 0.3% and 0.5% Pb and comparable standard deviation values of 3-4% for the lead content (Table 8.2).

However, deliberately added lead amounts, namely >4% Pb, point to different modes for the tin additions across the datasets. The lowest mode for tin is seen for Kalapodi, namely between 3% and 5% tin, while typically larger tin additions were noted for leaded bronze for Pherae and the tripods, (Figure 8.5). For the latter, fewer leaded objects were analysed on the whole but lead is typically added to bronze richer in tin with a mode of 9% tin, while no leaded tripods were found with contents below 6% tin. Both Kalapodi and the tripod datasets showed a relative absence of leaded objects with larger than 10% tin contents, while a single tripod fragment analysed with 11% tin is an exception. Meanwhile, in the Pheraean assemblage a marked difference was seen as tin concentrations for the leaded bronze group from Pherae have both higher mean and median values, as well as two modes at 7% and 11% tin (as also discussed in Chapter 6). In addition, the pattern of a bimodal distribution for the tin content in the leaded bronze group noted for Pheraean, did not seem to be duplicated in the Kalapodi or Delphi assemblages which both showed a rather normal, bell-curve distribution for their tin contents in both the binary and leaded bronze groups (Figure 8.5 & 8.21). Finally, all three assemblages showed a preference for low-lead ternary bronzes with frequent lead additions between 4% and 8% Pb and a small scatter of lead-rich objects (Figure 8.22).

8.1.1.2 Trace and minor elements

Due to methodological concerns, consideration of the trace elements between the sanctuary datasets focuses more on the patterns, correlations, and the spread in the values as illustrated by standard deviation levels rather than on the absolute values produced by the different analytical instruments. Average values for each element have been also discussed in order to reveal any patterns in the trace element fingerprint for the respective assemblages. Finally, any patterns discussed below are taken rather as indications worth further consideration in order to explore the limits of their validity.

Cobalt and nickel concentrations have been amongst the first to look at due to their possible relation to ore geology as opposed to elements which are more dramatically affected by successive metalworking treatments such as arsenic, zinc or iron (see also Chapter 5). Overlapping clusters for cobalt and nickel were visible for all three datasets with mean and median values of 0.02-0.04% for cobalt and 0.04-0.07% for nickel, whereas few nickel-rich outliers were only noted for Pherae along with a single cobalt-rich tripod (Figure 8.6 & 8.25). Finally, a more distinct pattern is visible for Pherae with typically lower cobalt values were found.

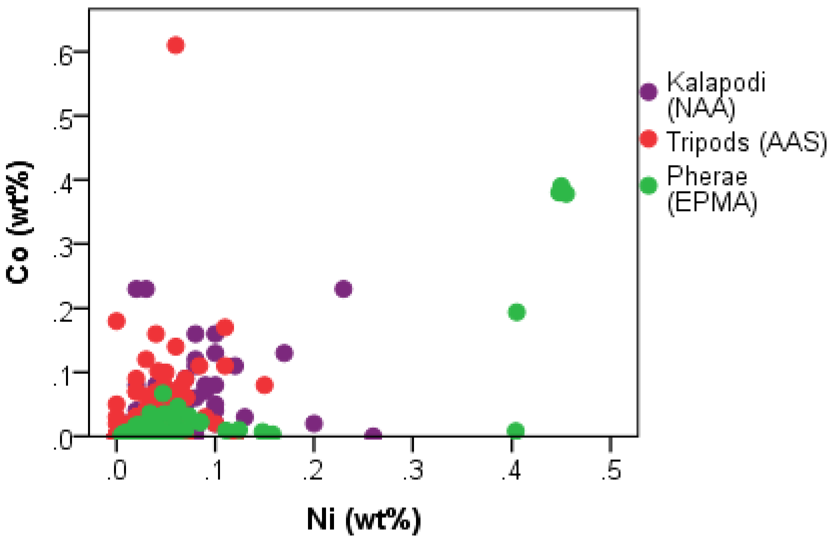


Figure 8.6. Scatterplot of nickel against cobalt for the Pherae (only EPMA), Kalapodi and the tripods from Delphi assemblages

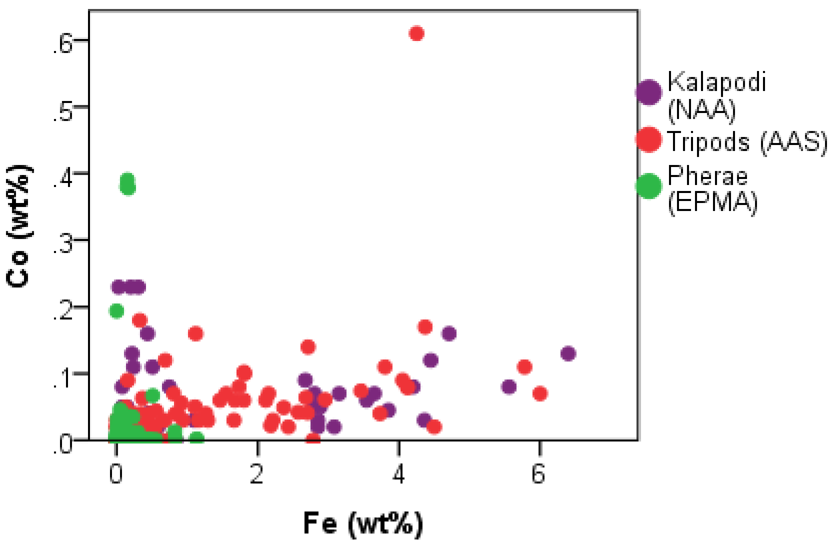


Figure 8.7. Scatterplot of iron against cobalt for the Kalapodi, Pherae and the tripods assemblages

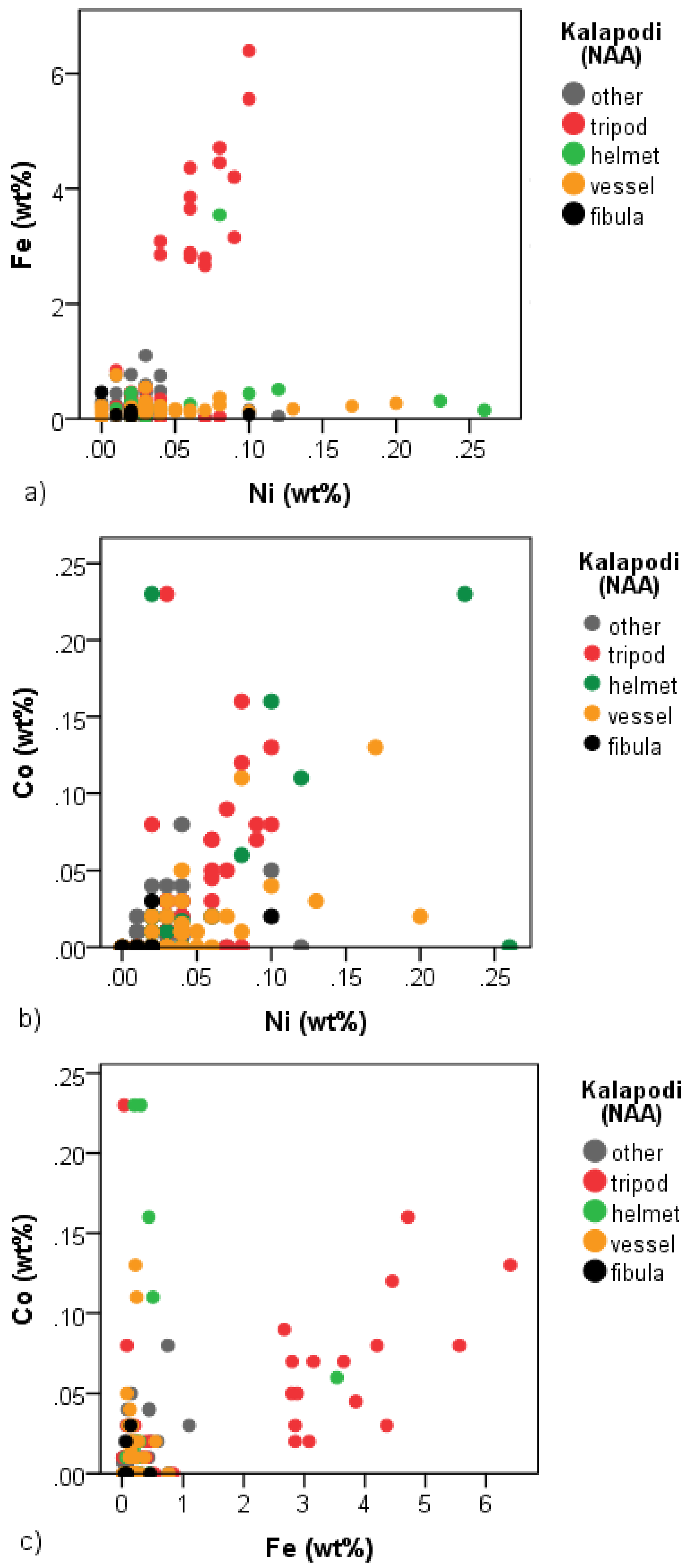


Figure 8.8. Scatterplots for the iron, nickel and cobalt contents in the Kalapodi assemblage according to artefact type where a distinct compositional cluster is visible for the tripods

Iron concentrations showed a similar pattern where the Pheraean assemblage with iron contents typically below 1% and a standard deviation of 0.2%, is somewhat differentiated from Kalapodi and the tripods which included several iron-rich objects with a maximum value of 6% for the tripods and standard deviations of 1.2-1.4% (Table 8.3, Figure 8.7). In addition, a distinct group emerged for Kalapodi with clustering iron and nickel values of approximately 1-3% iron and 0.05-0.1% nickel. Meanwhile, even though the cobalt content for this cluster showed rather dispersed values, these are typically higher than the rest of the sample (Figure 8.8)

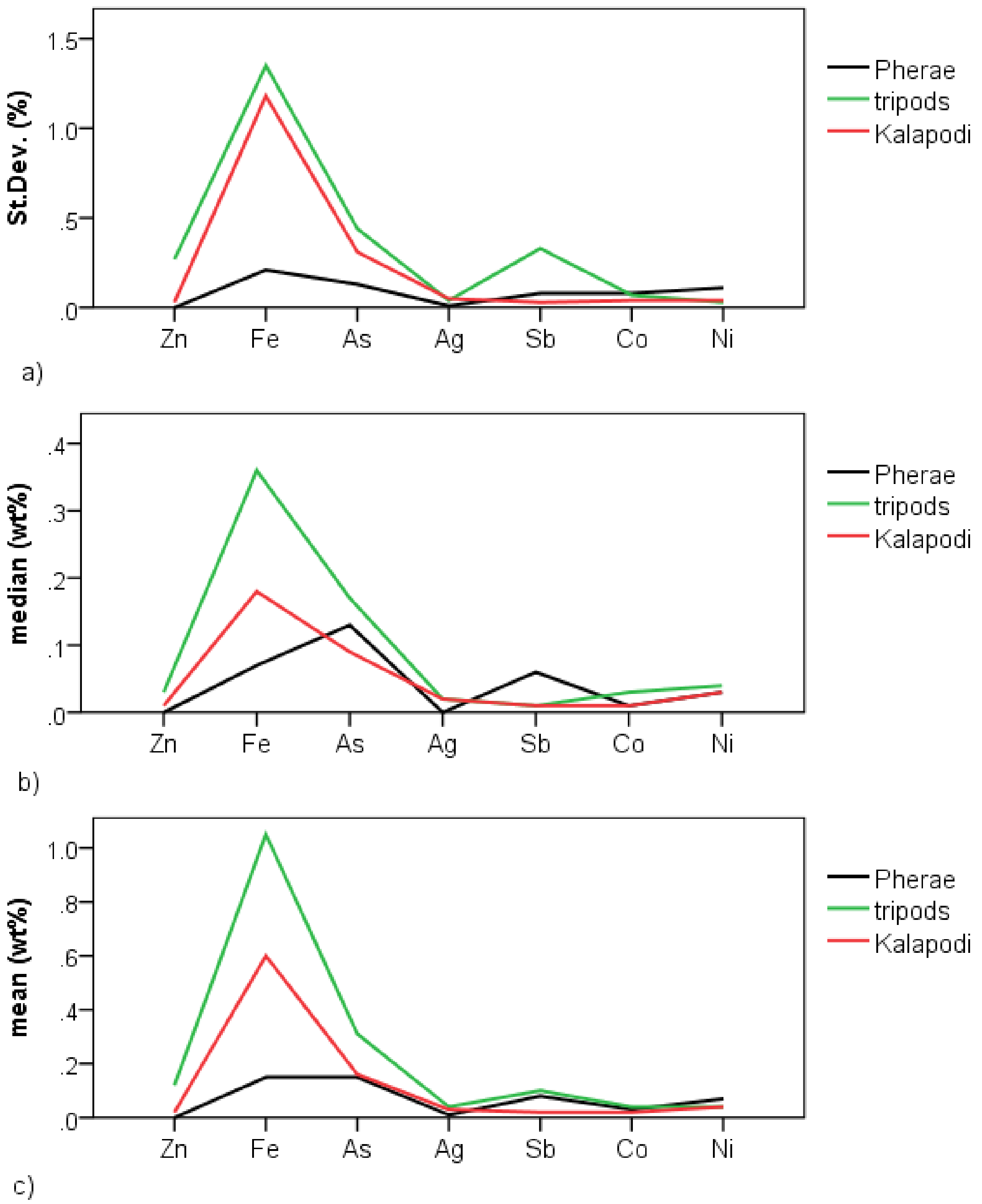


Figure 8.9. Line graphs for (A) the standard deviation, (B) median, and (C) mean values for the trace elements amongst the Pherae, Kalapodi and the tripods datasets

Interestingly, the group of objects from Kalapodi in this cluster belongs to a single artefact type, namely the tripods. An additional iron-rich object from Kalapodi is the helmet B 81 whose trace element fingerprint interestingly matches that of the tripods. Consequently, the similar trace element fingerprint of the Kalapodi tripods could point to a common production site as with the Delphi ones. Finally, comparable mean arsenic values for Kalapodi and the tripods should be primarily attributed to the presence of a few arsenic-rich outliers of around 2% arsenic, as median values were similar with values between 0.1% and 0.2% As (Figure 8.10, Table 8.3).

To sum up, there are certain indications that could suggest either the use of different copper ores for the Thessalian and central Greek workshops as seen in the characteristic cobalt values or, in fact, the practice of overall different metallurgical practices as could be reflected in the iron and arsenic concentrations.

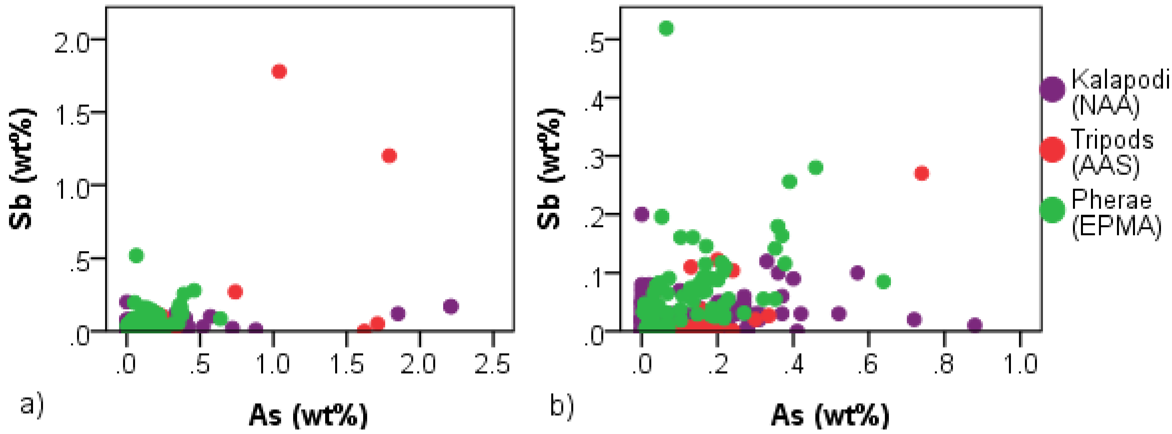


Figure 8.10. Scatterplots of arsenic against antimony for the Kalapodi, Pherae and the tripods assemblages; A) all values, B) excluding outliers

8.2 Burials and settlements: Lefkandi and Nichoria

Analyses of copper-based objects from the Toumba cemetery at Lefkandi in Euboea in central Greece and the settlement of Nichoria in southern Peloponnese are discussed below together (Figure 8.1). Despite their apparent geographical distance, they have been grouped due to their non-sanctuary provenance. In addition, they both include certain artefacts which are placed chronologically earlier than the sanctuary assemblages of the 8th and 7th centuries BC and closer to the Late Bronze – Early Iron Age transition at the beginning of the 1st millennium BC. For instance, four objects from Lefkandi dating to the Middle and Late Protogeometric periods in the 10th century BC are characteristic examples. Similarly, the material analysed from Nichoria which has been dated under rather broad chronological periods, namely Dark Age (DA) I-III which follow the Late Helladic (LH) period in the Late Bronze Age, included eight objects with a LH-DA I dating.

The Nichoria and the Lefkandi datasets showed an overall absence of leaded bronze in contrast with the Pheraean sample, while a single outlier from Nichoria with a 20% lead was analysed (Figure 8.11). Mean lead values for Lefkandi and Nichoria are both well below 1%, while they both showed a median of 0.2% lead (Table 8.2).

The above pattern for the lead concentrations in the Lefkandi and Nichoria analyses comes in distinct contrast with those for the sanctuary assemblages which all included leaded objects with variable lead contents up to 29% Pb (Figure 8.4). Furthermore, the circumstances of the analysis of the lead-rich outlier seen in the Nichoria XRF dataset (collar N 1335 in Rapp *et al.* 1978, p. 173, table 11.4) pose further issues of data reliability as the XRF analyses was conducted on the object's surface which has been also classified as *'B'* (from a scale between *'A'* for good metallic surface and *'E'* for heavy corrosion in the form of green malachite patina [for more information on the corrosion scale see Rapp *et al.* 1978, pp. 171-172]) suggesting that it must have been affected by corrosion products at least at some degree. However, even if this lead value is moderated by -30% as suggested by comparative surface and invasive analyses (see discussion in Chapter 3), it still points to the presence of leaded bronze at Early Iron Age Nichoria. Finally, comparison of these results with the lead-free ones from the metal prills and amorphous lumps from the metalworking site at Nichoria, suggest that the collar N 1335 was manufactured elsewhere and that was rather brought on site. Meanwhile, absence of leaded bronze from Lefkandi make an even bigger impression taking into consideration the close proximity to Kalapodi and Delphi in central Greece.

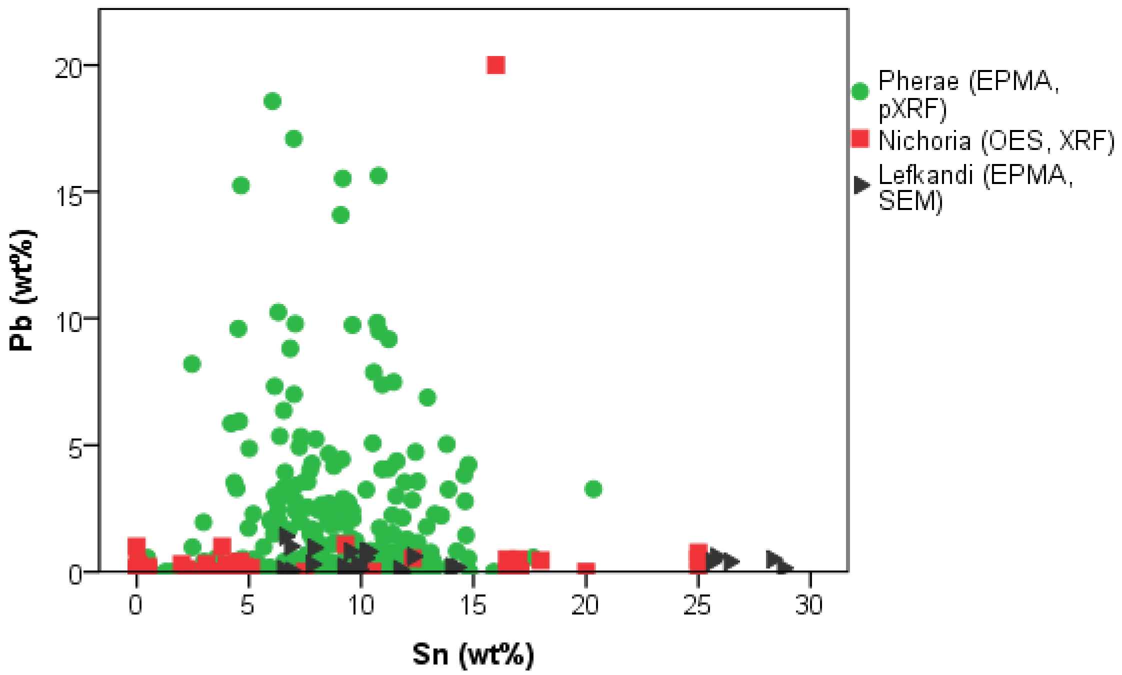


Figure 8.11. Scatterplot of tin against lead for the copper-based objects analysed from Lefkandi, Nichoria and Pherae

Tin values in Nichoria and Lefkandi showed some variation from Pherae as values >15% were more commonly found (Figure 8.11). However, this is better understood when considering the circumstances of these analyses in more detail. At a first glance, overall large variation from unalloyed copper to tin-rich bronze with more than 20% Sn is seen. This is also mirrored in the high standard deviation values of 8% for both Nichoria and Lefkandi which are larger by at least 5% in comparison to the rest of the datasets discussed here (Table 8.2).

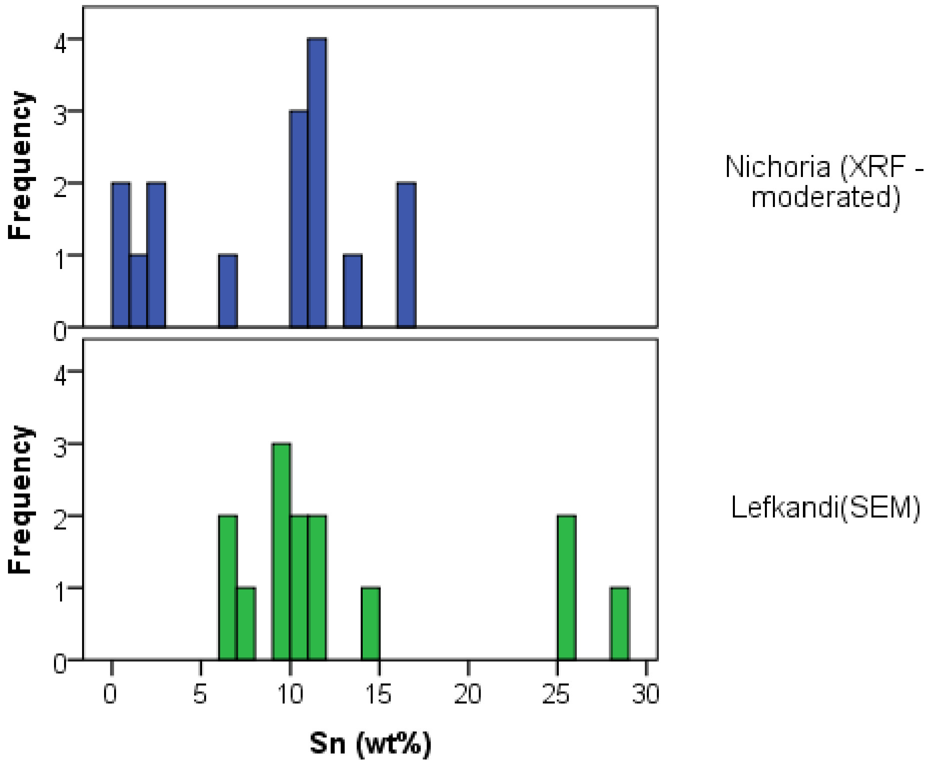


Figure 8.12. Barchart for the tin distribution in the objects' analyses from Nichoria (XRF only) and Lefkandi (SEM only); tin values from Nichoria have been moderated by -35% to account for expected overestimation during analyses of objects' surfaces

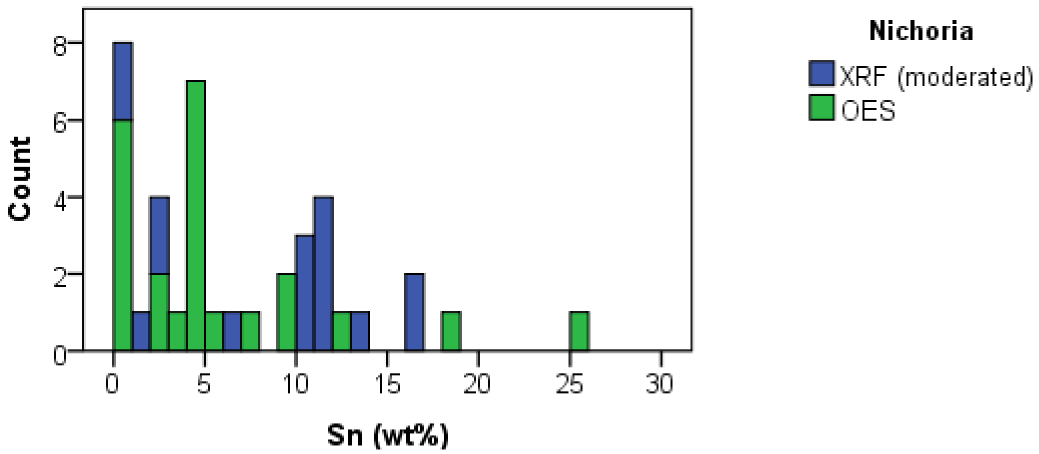


Figure 8.13. Histogram for the tin distribution in the Nichoria assemblage as analysed with OES and XRF; the latter values have been moderated (-35%)

In order to understand better these high tin values, the analytical methodology for Nichoria and certain particularities of the Lefkandi sample need to be addressed. Thus, for Nichoria the surface, non-invasive XRF analyses on the objects' intact surface, i.e. including any corrosion patina, would have produced higher tin values than the sound metal core as already proven above (Chapter 3.2.4, Figure 3.23). As shown by the comparative investigation of surface pXRF and invasive EPMA analyses, a tin value of 17.5% or 15% as analysed with the pXRF on a bronze object's intact or corrosion-free (scraped) surface respectively could be as little as 10%. Moderating these tin-rich analyses from Nichoria by approximately 30-40% of the analysed values showed comparable tin values with the rest of the datasets. As a result, the argument for the lack of consistency in the metallurgical and alloying practices at Nichoria on the basis of the great variation in the tin values (Rapp *et al.* 1978, p. 178) as seen in Figure 8.21 needs revising. Looking at the moderated XRF tin values for Nichoria in comparison with the Lefkandi analyses they both show a pattern for an average 10% tin lead-free binary bronze when copper is alloyed (Figure 8.12) which also matches the OES results for Nichoria.

Thus, the two tin-rich objects analysed with the XRF from Nichoria which originally gave tin contents of 25% Sn, namely shield boss N 1833 and pin N 1789, following the tin moderation and considering preservation state (B), end up with tin concentrations of around 16% which is not considered as exceptionally high as such values were not rare for Early Iron Age Greece. Similarly, the tin-rich prill (4448) analysed with the OES with 18% tin should be rather taken as an indication for alloying of copper taking place on site and not necessarily as a high-tin bronze artefacts. This prill should be rather compared to the results from tin-rich prills in the crucible fragment AE 215 from Pherae with 17-23% tin (see also Chapter 6.3.2) or the workshop residue droplet B 1971 from Kalapodi with 22% tin, and should be too regarded as evidence for an intermediate step in the alloying process. The last tin-rich alloy seen in Nichoria which comes from a small cylinder (SF 4842) and whose OES analyses showed 25% tin, is a unique find and is hereby considered as an outlier while it still underlines the circulation lead-rich bronzes amongst Early Iron Age communities.

Tin-rich results from the Lefkandi cemetery with tin contents between 26% and 29% Sn confirmed both by the SEM and EPMA analyses (Orfanou and Rehren forthcoming, Orfanou 2009) need further consideration. These compositions of exceptionally high tin bronzes have been obtained from what has been regarded to be a single tin-rich artefact which melted during the pyre and was then deposited in the burial along with the burnt bones (Figure 8.19). On the basis of the tin-rich composition, but also on the overall burial context of the pyre, it has been suggested that this object was an import brought at Lefkandi possibly from the East.

Finally, trace element concentrations for Nichoria and Lefkandi hereby discussed revealed no further particularities either in their average or standard deviation values which are comparable to those from the rest of the datasets (Figure 8.25 & 8.26).

8.3 Craddock's analyses from Early Iron Age Greece

The group of objects analysed by Craddock are not considered as a distinct group as they came from various sites from all over Greece while their dating was not particularly narrow as also argued by Craddock himself (1977, p. 103) while they better represented the chronologically lower half of the period, namely the 7th and 6th centuries BC (Figure 8.16, also Table 7.2). The various objects examined have been attributed broadly to either the Geometric or Archaic chronological periods, while their vast majority were attributed to the latter as only six Geometric objects have been analysed, namely a spearhead, an axe, and four tripods, as emphasis on the 1976 publication was put on material from the Late Bronze Age rather than on the Geometric and Protogeometric periods (Craddock 1976).

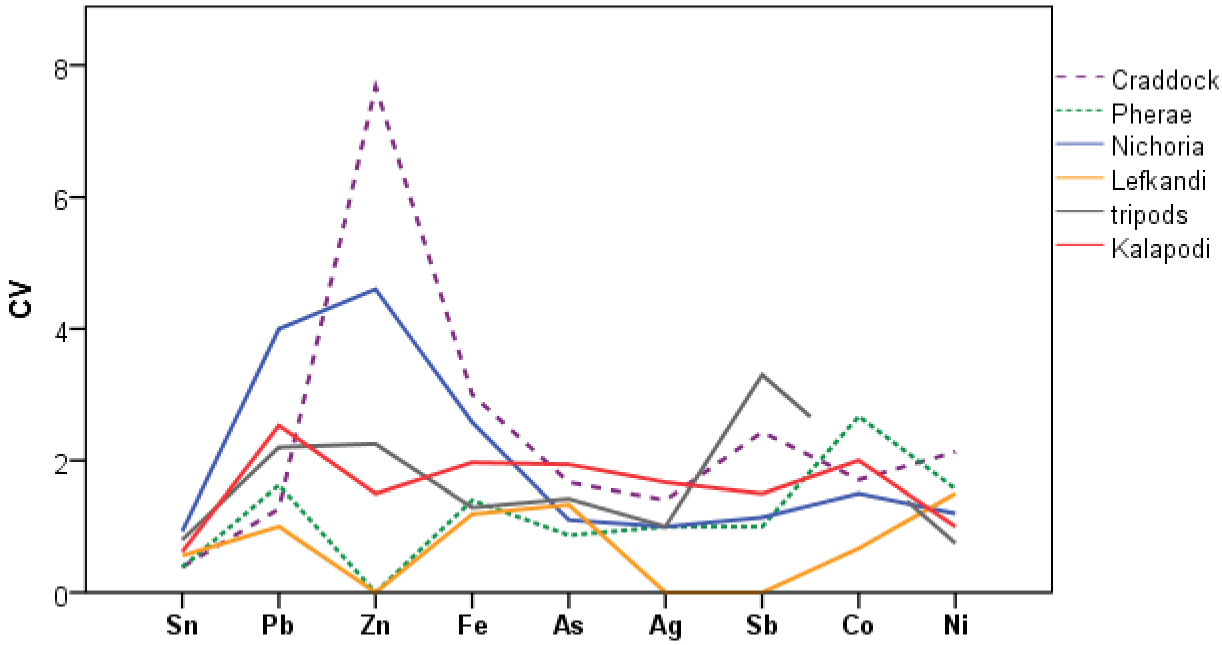


Figure 8.14. Line graph illustrating the coefficient of variation (CV) between the different analysed assemblages for each element

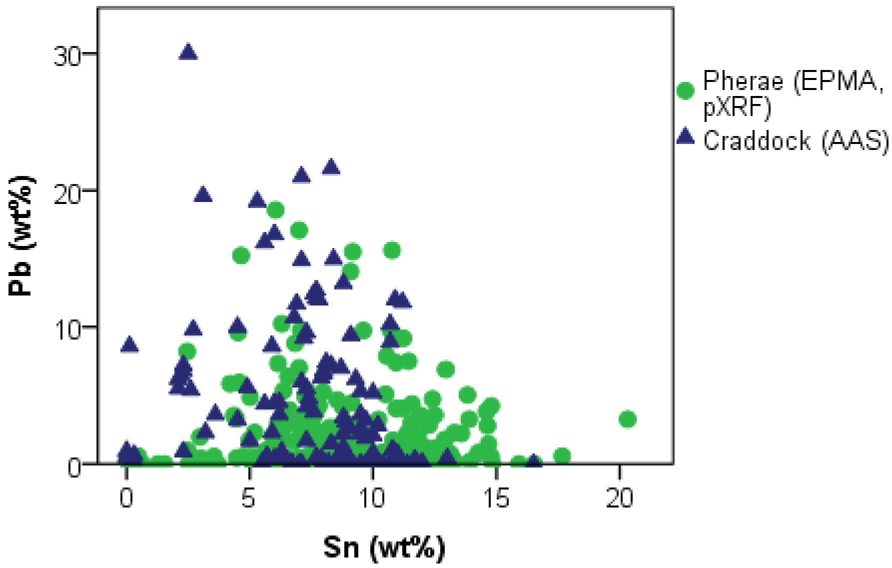


Figure 8.15. Scatterplot of tin against lead for the Pheraean assemblage and the one analysed by Craddock (1976; 1977)

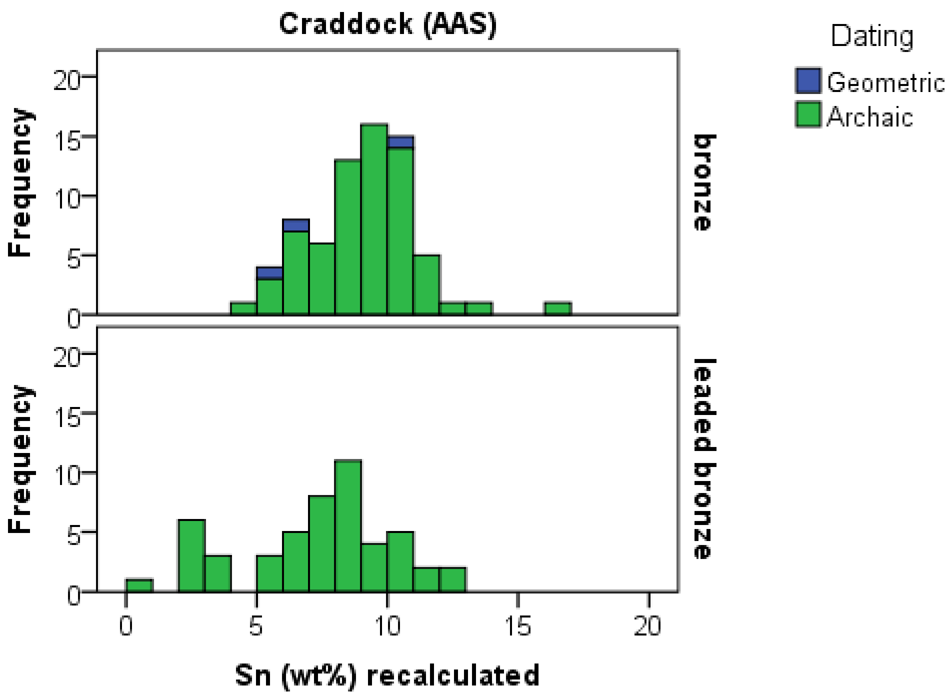


Figure 8.16. Histograms for the tin distribution (recalculated/renormalised after lead content was subtracted from the totals) in the analyses by Craddock according to chronological periods

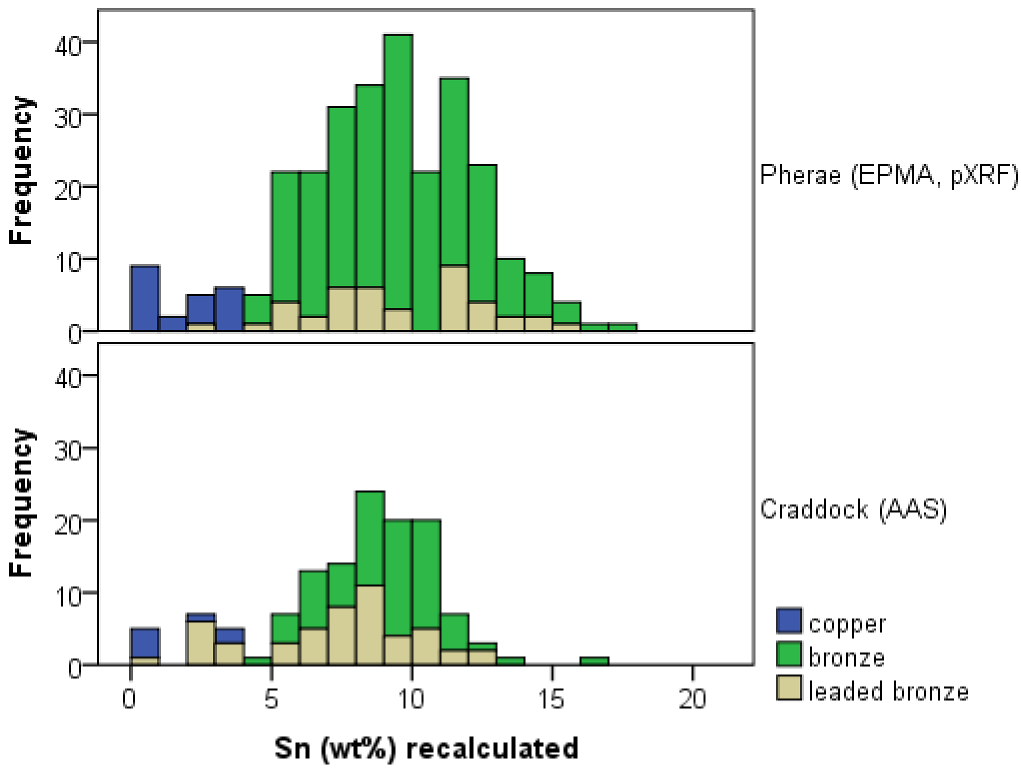


Figure 8.17. Histograms of tin distribution (recalculated after lead was subtracted from the totals) for the Lefkandi, Nichoria and the materials analysed by Craddock; XRF Nichoria values not moderated

Standard deviation values for tin at 3% in Craddock's assemblage match those for the rest of the analysed samples (typically 3-4%), whereas a 6% standard deviation for lead is somewhat higher than those in the rest of the samples also at 3-4% (Table 8.2). Larger than the average standard deviations were noted for the trace elements which could be justified by the mixed origins and typology of the sample. In the comparative line graph for the CV levels in the minor elements for all the datasets discussed here, Craddock's analyses are found towards the high end of the spectrum, while the values for tin and lead are found at the low end of the values' spectrum (Figure 8.14). Nonetheless, emphasis should be put on the tin and lead results which reveal an underlining alloying pattern for the 7th and 6th centuries in Greece.

Both Craddock's analyses and those from Pherae showed the relative absence of unalloyed copper with only 5% and 7% of the total analysed samples respectively and an overall preference for tin-bearing alloys (Table 8.1). Craddock's analyses also relate to Pherae as they are the datasets where leaded bronze is best represented despite that leaded bronze was found more frequently with 39% of the sample as opposed to 15% for Pherae. This pattern was also reflected in the average values for tin which are larger for Pherae with 9% Sn as opposed to 8% for Craddock's analyses, and the mean values for lead at 2% and 4.5% Pb respectively (Table 8.2). Meanwhile, it is interesting to note that despite the large population of leaded bronze artefacts, none of these date to the Geometric period (Figure

8.16), while this should not be over-interpreted since, as already mentioned, the group of Geometric bronzes is overall quite small including only six objects.

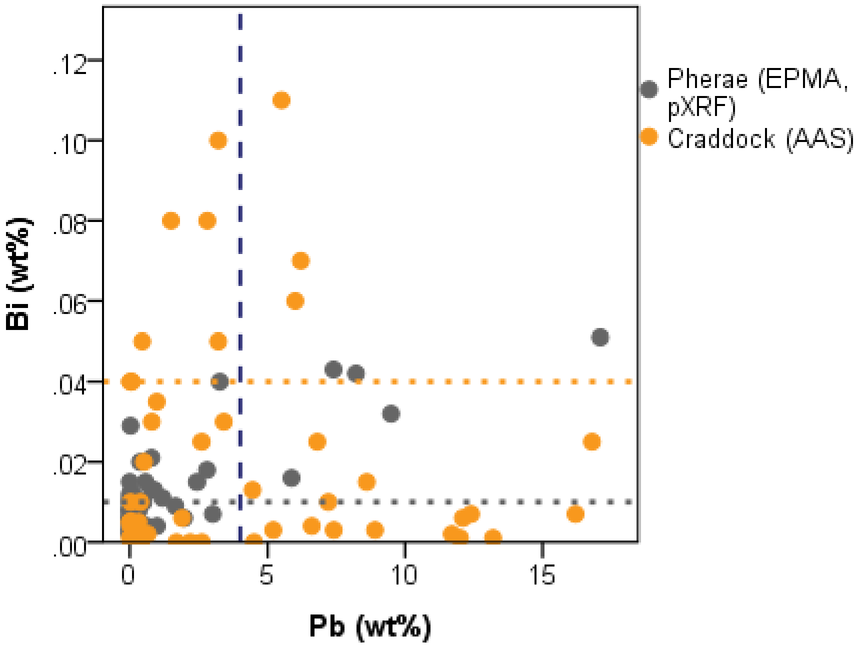


Figure 8.18. Scatterplot of lead against bismuth for Craddock's and Pherae analyses; blue dotted line at 4% lead distinguishes between lead impurities and intentional additions; grey and orange dotted lines at mean Bi values for Pherae and Craddock's analyses respectively

Finally, mean and median trace element concentrations, and overall patterns, as also seen in the analyses from Nichoria and Lefkandi, do not differ substantially from the picture emerging for the Greek Early Iron Age (Figure 8.20). Higher mean values for bismuth seen in Craddock's analyses also match the aforementioned overall larger lead values (Table 8.3) and could be taken as an indication for a correlation between lead and bismuth as seen for Pherae (Figure 8.18 & 6.21).

Table 8.1. Summary table of the metals/alloys present in the datasets mentioned in the chapter (the two zinc-rich objects in the Pheraean assemblage have been hereby excluded)

	N				N (%)			
	copper	bronze	leaded bronze	total	copper	bronze	leaded bronze	total
Pherae	19	220	41	280	7	79	15	100
Kalapodi	34	105	15	154	22	68	10	100
Tripods	54	53	8	115	47	46	7	100
Craddock	7	71	50	128	5	55	39	100
Nichoria	14	24	1	39	36	62	3	100
Lefkandi	0	14	0	14	0	100	0	100
other	51	64	40	155	33	41	26	100
Total	**179**	**545**	**172**	**896**	**20**	**63**	**17**	**100**

Table 8.2. Summary table for the tin and lead contents in the datasets mentioned in the chapter

sample	Pherae	Kalapodi	Nichoria	Lefkandi	Greece	Tripods
analyses	Orfanou 2014 EPMA, pXRF	Riederer 2007 NAA	Rapp et al. 1978 OES, XRF	Orfanou 2009 EPMA, SEM	Craddock 1976; 1977 AAS	Rolley et al., 1983 Marangou et al., 1986 AAS
N	282	154	39	14	128	115
			Sn (wt%)			
Mean	8.7	6.1	8.6	13.4	7.6	5.0
Median	9.0	6.6	4.6	10.0	8.2	4.8
Min	0.0	0.0	0.0	6.6	0.0	0.0
Max	20.3	21.8	25.0	28.8	16.5	14.6
St. Dev.	3.3	3.8	8.0	7.5	3.0	4.0
CV	0.38	0.62	0.93	0.56	0.39	0.80
			Pb (wt%)			
Mean	1.9	1.7	0.8	0.4	4.5	1.5
Median	0.5	0.3	0.2	0.2	2.2	0.8
Min	0.0	0.0	0.0	0.0	0.0	0.0
Max	18.58	29.6	20.0	1.4	30.0	23.0
St. Dev.	3.1	4.3	3.2	0.4	5.7	3.3
CV	1.63	2.53	4.00	1.00	1.27	2.20

8.4 Pherae in the bigger picture

Overall mean tin values have been found between 5% and 13% tin for the Delphi tripods and Lefkandi respectively, while typically small lead contents were found with median values below 1% Pb, with the exception of Craddock's analyses where two out of five objects are of leaded bronze (Table 8.2).

Looking at the alloy recipes as analysed in the Pherae sample in comparison to the rest of the datasets, a quite comparable pattern emerges for the Thessalian site with the majority of the objects to be from binary bronze (79% of the Pherae analysed sample), and fewer from leaded bronze (15%) or unalloyed copper (7%) (Table 8.1). Meanwhile, leaded objects occur more frequently at Pherae (39% of the sample) than in the rest of the analysed assemblages (Figure 8.22).

High-tin bronze alloys were quite rarely found and have been detected in just a couple of objects from Lefkandi and Nichoria with contents of 25-29% tin, while the rest of the binary or leaded bronzes typically do not contain more than 18% tin (Figure 8.19). Lead is usually found in amounts smaller than 20% Pb, even though certain lead-rich outliers occur in the Kalapodi, Craddock and the tripods datasets with values of up to 30% lead. For Pherae a distinct pattern emerges where 10-15% tin bronzes have been leaded with variable, typically low additions of up to approximately 8% Pb which was not seen in the rest of the datasets discussed here. However, the above could be revisited if pXRF results are moderated as dictated by methodological concerns (see Chapter 3).

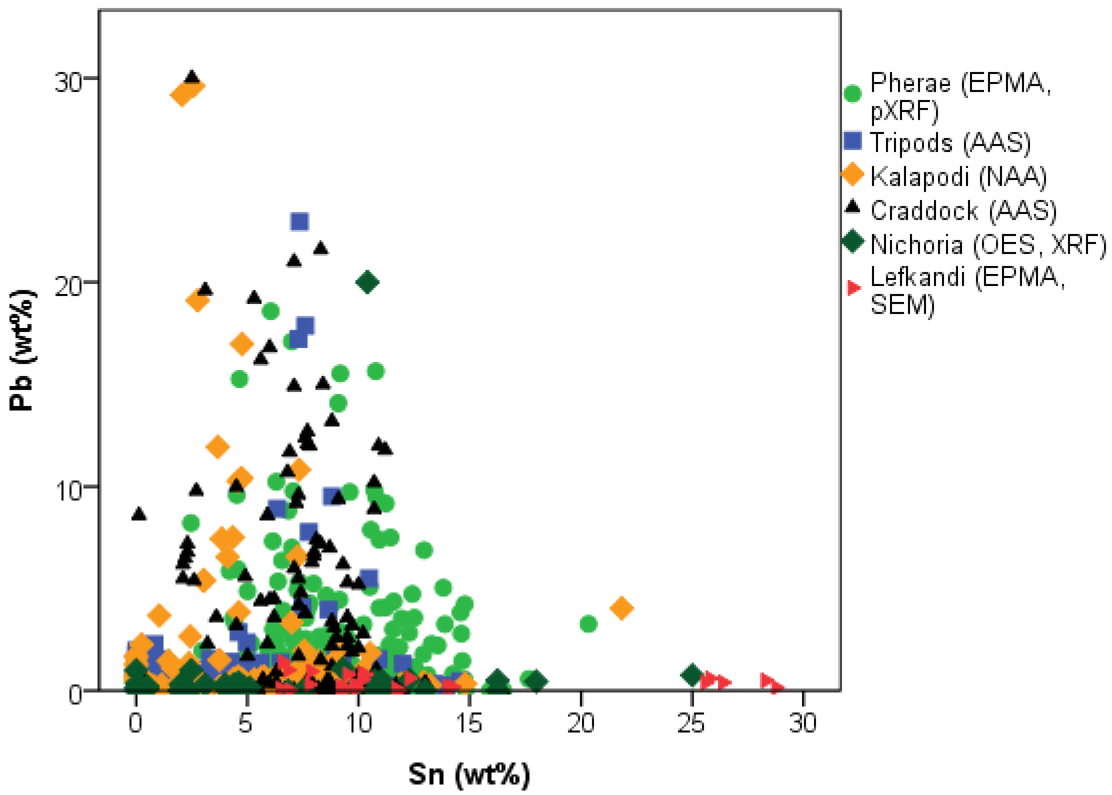


Figure 8.19. Scatterplot of tin against lead for the different assemblages from Early Iron Age Greece, including Pherae; XRF tin values for Nichoria and pXRF lead values for Pherae have been moderated

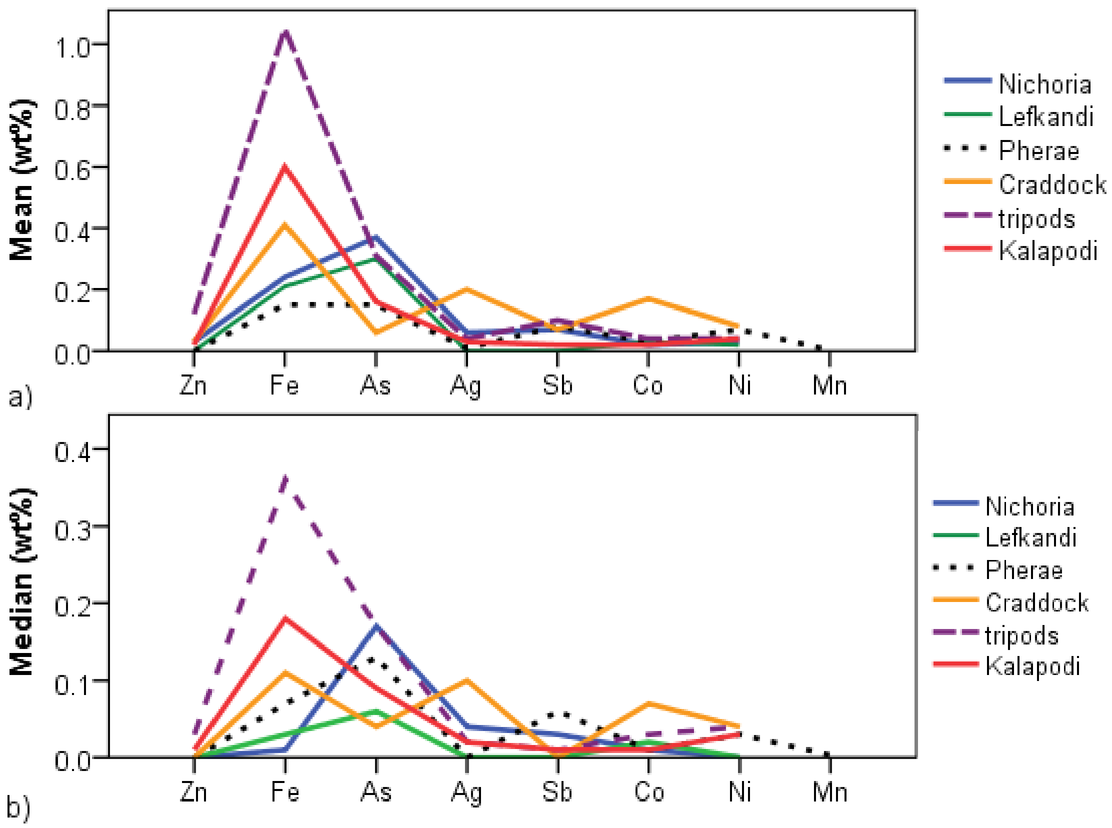


Figure 8.20. Line graph for (A) the mean and (B) median values of the trace element concentrations in the various analysed datasets

In the trace element concentrations, overall similarities are visible to a large degree amongst the different datasets with mean and median values which match those of impurities typically occurring in ancient copper and its alloys including arsenic and zinc (Table 8.3). However, certain particularities have been found in the patterns of each assemblage's trace element fingerprint. Thus, a pattern where average values for either iron or arsenic are larger. For instance, both higher mean and median values for iron are seen in the tripods, Kalapodi and Craddock's analyses, while analyses from Pherae along with those from Nichoria and Lefkandi typically show higher arsenic values (Figure 8.20 & 8.27). The above is hereby merely reported as an observation and, at this stage, it is not interpreted as to reflect any significant variation in the metallurgical technology given the large variation in the artefact types, sites, and analytical techniques involved.

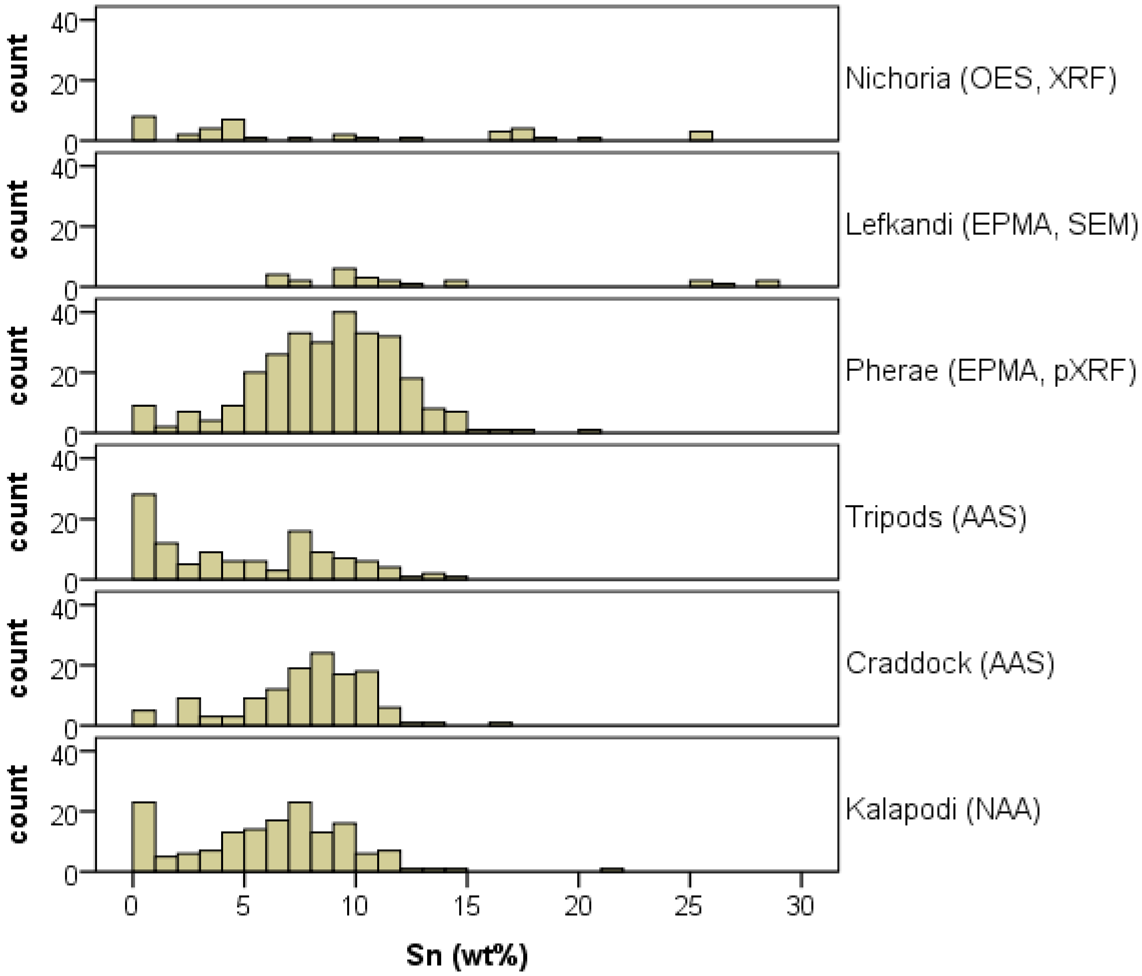


Figure 8.21. Histograms of tin distribution in the different Early Iron Age copper-based assemblages; XRF Nichoria values not moderated

Arsenic and iron have both showed the highest mean and median values amongst the trace elements analysed for all datasets and are higher than zinc, silver, antimony, cobalt, nickel and manganese. A single exception is again seen in the analyses by Craddock which has produced higher silver and cobalt average values in relation to the rest of the datasets (Figure 8.25). Maximum arsenic values have been found at approximately 2% As for the tripods and Kalapodi analyses (Figure 8.27). These arsenic contents which would have been sufficient to argue for the composition of arsenical copper-alloys, are hereby taken rather as outliers given the compositions of the overall analysed samples from the two central Greek sanctuaries, including their Iron Age dating when arsenical copper/bronze would have been widely put out of use and production.

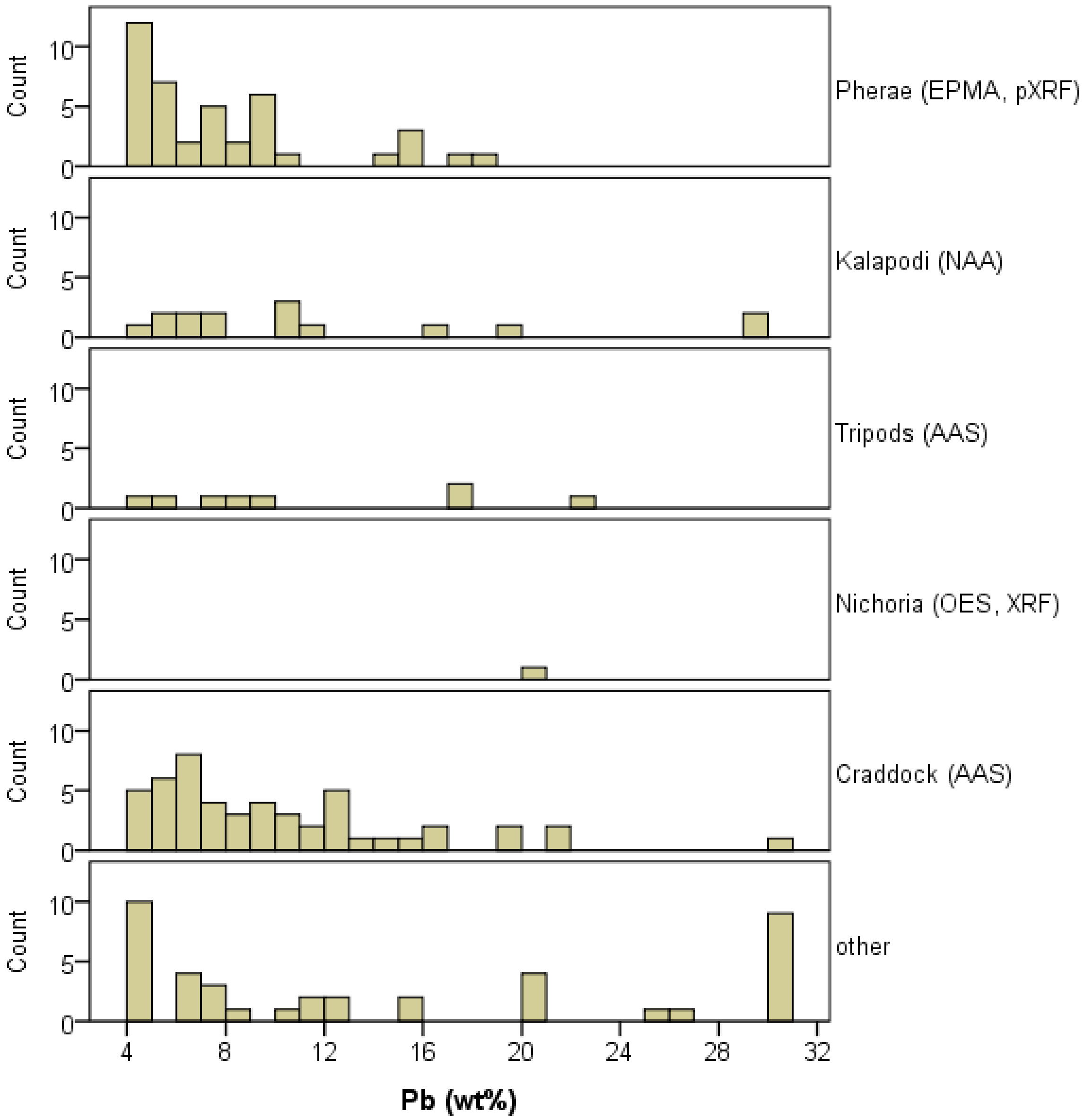


Figure 8.22. Histograms of the lead distribution in the datasets mentioned in the chapter (Lefkandi dataset has been excluded as no leaded artefacts have been analysed)

The two highest arsenic contents found in a couple of vessel fragments from Kalapodi with 2.2% arsenic, namely B 1328 and B 1456, taking into consideration the overall alloy recipes of these vessels which also contain 3% tin, and 1% and 5% lead respectively, and their late dating in the 6th century BC, should be considered as accidentally present possibly from mixing scrap arsenical alloys or from a particular copper ore used (Riederer 2007, pp. 404, 413). Similarly, maximum values of zinc at 2% and mean below 0.2% Zn also do not point to its deliberate addition, but rather to its occurrence as an impurity (with the exceptions found in Pherae discussed in Chapter 4.2.4). Meanwhile, no additional disparities were seen in the minor and trace element concentrations for the analysed Early Iron Age datasets which all showed rather low and well-clustered values.

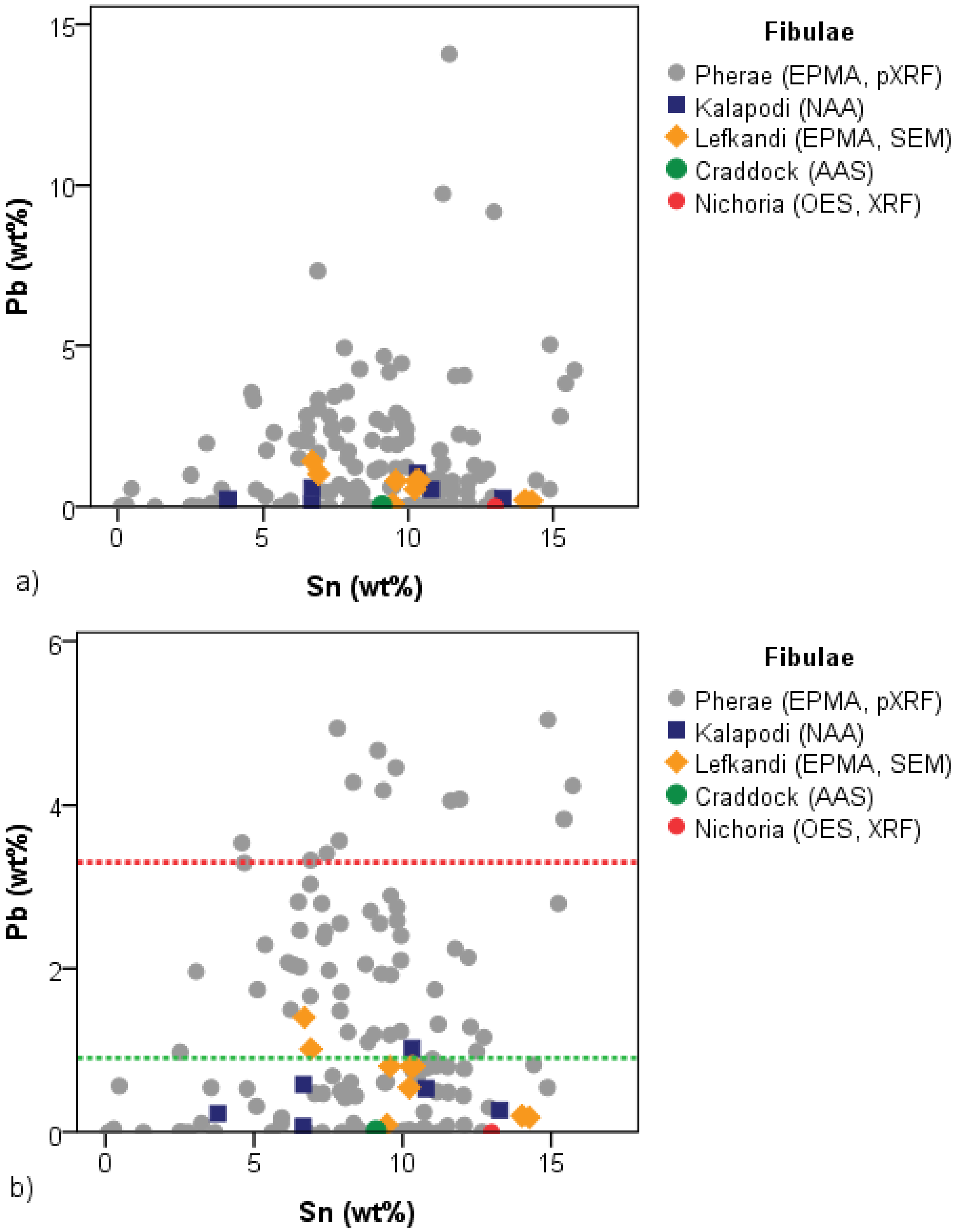


Figure 8.23. Scatterplot of tin against lead for the fibulae analysed in the assemblages from Pherae, Kalapodi, Lefkandi, Nichoria, and Craddock's; (B) is a close up of (A); in (B) green and red dotted lines represent median lead values for the Thessalian and Epirotic fibulae in the Pherae assemblage

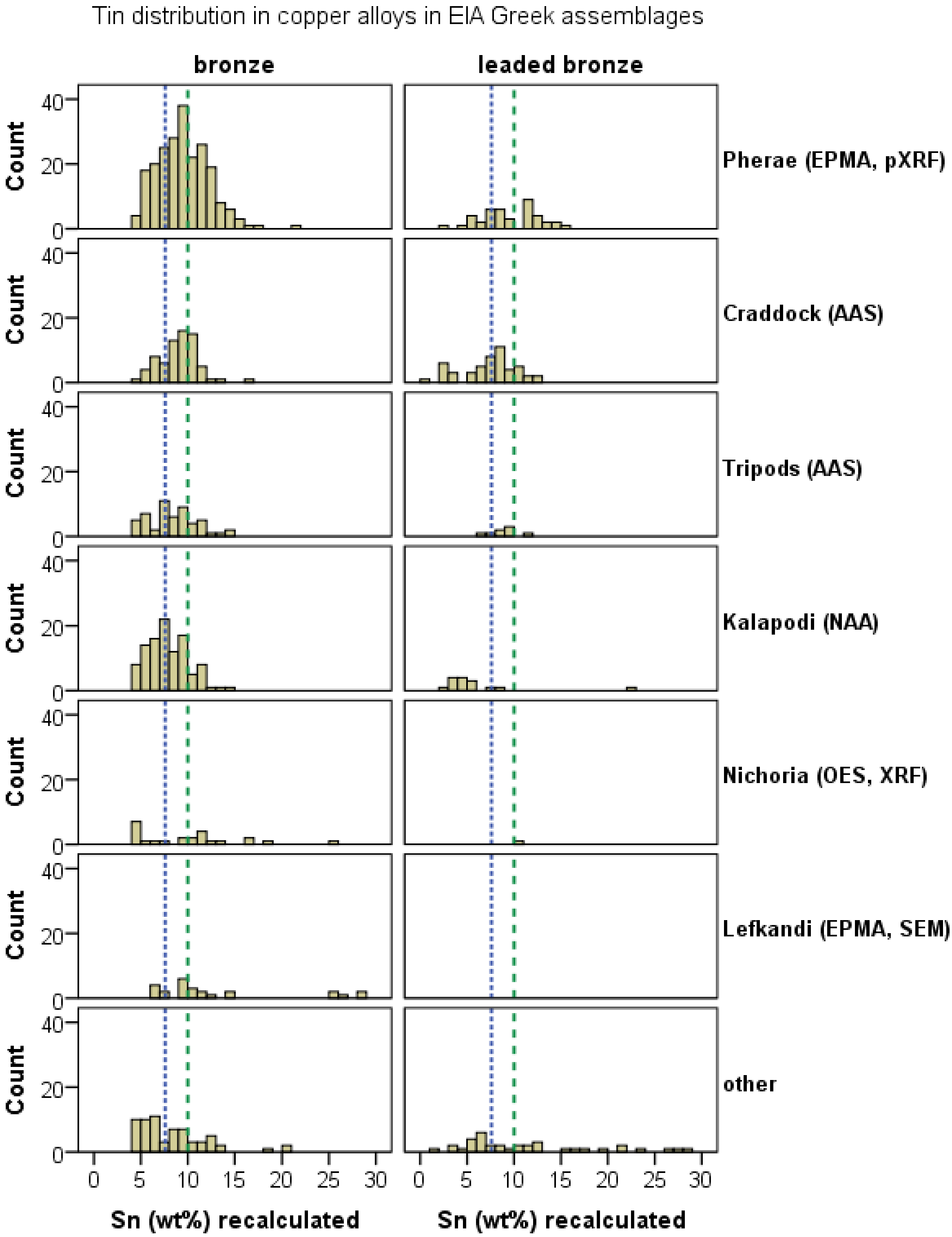


Figure 8.24. Histograms for the tin distribution in the different datasets according to alloy type, i.e. binary or leaded bronze; tin values recalculated after lead content was removed from the totals; XRF generated tin content for Nichoria moderated; green dotted line indicates a tin content of 10%, i.e. the optimum tin bronze, and blue dotted line at 7.6% represents the overall mean value for tin (though including the group of unalloyed copper objects)

Finally, results from the fibulae analysed across the different samples were put together in order to explore further the patterns already noted for Pherae (see Chapter 7.3.1). Comparison of the bulk composition of the fibulae included in the datasets from Kalapodi, Lefkandi, Nichoria and Craddock's analyses, to those from Pherae revealed a certain overlap for the major elements (Figure 8.23). Both the tin and lead concentrations for all the fibulae, apart from Pheraean sample, showed compositions of binary bronze with 4-14% tin and of 0-2% lead. The above overall compositions makes these fibulae comparable to the compositions of the Thessalian and Helladic/Attic-Boeotian groups seen in Pherae results, while they further highlighted the particularity of the Epirotic fibulae and their typically higher lead contents with a median values of 3.3% Pb as opposed to 0.9% Pb for the Thessalian (Figure 8.23 & 7.22b).

Table 8.3. Summary table for the trace elements in the datasets mentioned in the chapter

	sample	Pherae	Kalapodi	Nichoria	Lefkandi	Greece	Tripods
	analyses	Orfanou 2014 EPMA	Riederer 2007 NAA	Rapp et al. 1978 OES	Orfanou 2009 EPMA, SEM	Craddock 1976; 1977 AAS	Rolley et al., 1983 Marangou et al., 1986 AAS
N		70	154	23	14	128	115
Zn	Mean	0.00	0.02	0.05	0.00	0.03	0.12
	Median	0.00	0.01	0.00	0.00	0.00	0.03
	St.Dev.	0.00	0.03	0.23	0.00	0.23	0.27
	CV	0.00	1.50	4.60	0.00	7.67	2.25
Fe	Mean	0.15	0.60	0.19	0.21	0.41	1.05
	Median	0.07	0.18	0.03	0.03	0.11	0.36
	St.Dev.	0.21	1.18	0.49	0.25	1.23	1.35
	CV	1.40	1.97	2.58	1.19	3.00	1.29
Ni	Mean	0.07	0.04	0.05	0.02	0.08	0.04
	Median	0.03	0.03	0.04	0.00	0.04	0.04
	St.Dev.	0.11	0.04	0.06	0.03	0.17	0.03
	CV	1.57	1.00	1.20	1.50	2.13	0.75
Ag	Mean	0.01	0.03	0.06	0.00	0.20	0.04
	Median	0.00	0.02	0.04	0.00	0.10	0.02
	St.Dev.	0.01	0.05	0.06	0.00	0.28	0.04
	CV	1.00	1.67	1.00	0.00	1.40	1.00
Sb	Mean	0.08	0.02	0.07	*n.a*	0.07	0.10
	Median	0.06	0.01	0.03	*n.a*	0.00	0.01
	St.Dev.	0.08	0.03	0.08	*n.a*	0.17	0.33
	CV	1.00	1.5	1.14	0.00	2.43	3.30
As	Mean	0.15	0.16	0.21	0.30	0.06	0.31
	Median	0.13	0.09	0.15	0.06	0.04	0.17
	St.Dev.	0.13	0.31	0.23	0.40	0.10	0.44
	CV	0.87	1.94	1.10	1.33	1.67	1.42
Co	Mean	0.03	0.02	0.02	0.03	0.17	0.04
	Median	0.01	0.01	0.01	0.02	0.07	0.03
	St.Dev.	0.08	0.04	0.03	0.02	0.29	0.07
	CV	2.67	2.00	1.50	0.67	1.71	1.75

Table 8.3 Continued

	sample	Pherae	Kalapodi	Nichoria	Lefkandi	Greece	Tripods
	analyses	Orfanou 2014 EPMA	Riederer 2007 NAA	Rapp et al. 1978 OES	Orfanou 2009 EPMA, SEM	Craddock 1976; 1977 AAS	Rolley et al., 1983 Marangou et al., 1986 AAS
N		70	154	23	14	128	115
Se	Mean	0.02	n.a	n.a	*n.a*	*n.a*	*n.a*
	Median	0.02	n.a	n.a	*n.a*	*n.a*	*n.a*
	St.Dev.	0.02	n.a	n.a	*n.a*	*n.a*	*n.a*
	CV	1.00	n.a	n.a	*n.a*	*n.a*	*n.a*
S	Mean	0.03	*n.a*	n.a	0.07	*n.a*	*n.a*
	Median	0.02	*n.a*	n.a	0.01	*n.a*	*n.a*
	St.Dev.	0.03	*n.a*	*n.a*	0.11	*n.a*	*n.a*
	CV	1.00	*n.a*	*n.a*	1.57	*n.a*	*n.a*
Bi	Mean	0.01	*n.a*	0.01	*n.a*	0.04	*n.a*
	Median	0.01	*n.a*	0.01	*n.a*	0.01	*n.a*
	St.Dev.	0.01	*n.a*	0.01	*n.a*	0.19	*n.a*
	CV	1.00	*n.a*	1.00	*n.a*	4.75	*n.a*
Mn	Mean	0.00	*n.a*	*n.a*	*n.a*	*n.a*	*n.a*
	Median	0.00	*n.a*	*n.a*	*n.a*	*n.a*	*n.a*
	St.Dev.	0.00	*n.a*	*n.a*	*n.a*	*n.a*	*n.a*
	CV	0.00	*n.a*	*n.a*	*n.a*	*n.a*	*n.a*
Au	Mean	*n.a*	*n.a*	0.03	*n.a*	0.02	*n.a*
	Median	*n.a*	*n.a*	0.00	*n.a*	0.01	*n.a*
	St.Dev.	*n.a*	*n.a*	0.07	*n.a*	0.02	*n.a*
	CV	*n.a*	*n.a*	2.30	*n.a*	1.0	*n.a*

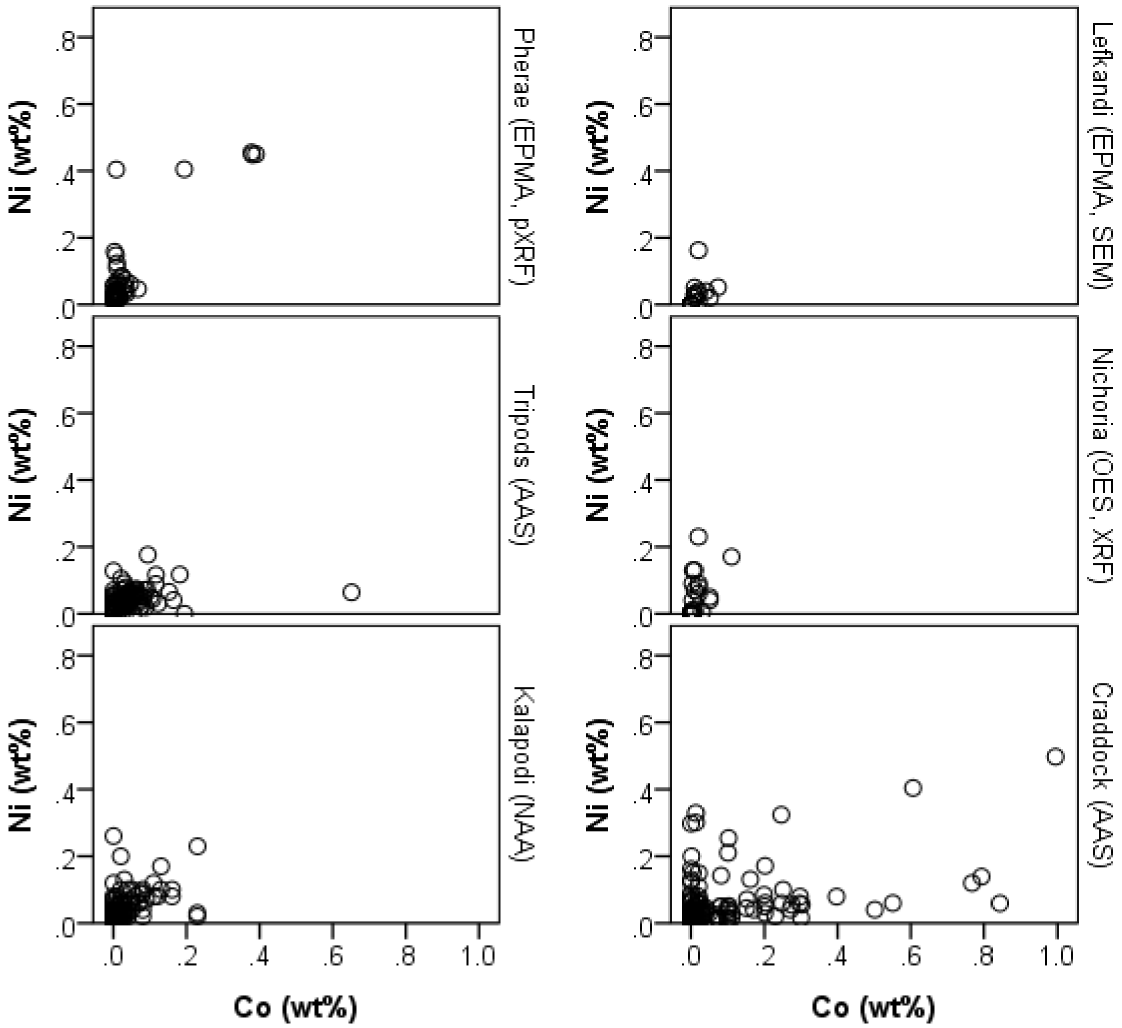


Figure 8.25. Scatterplots of cobalt against nickel for the different Early Iron Age assemblages (note: only OES for Nichoria)

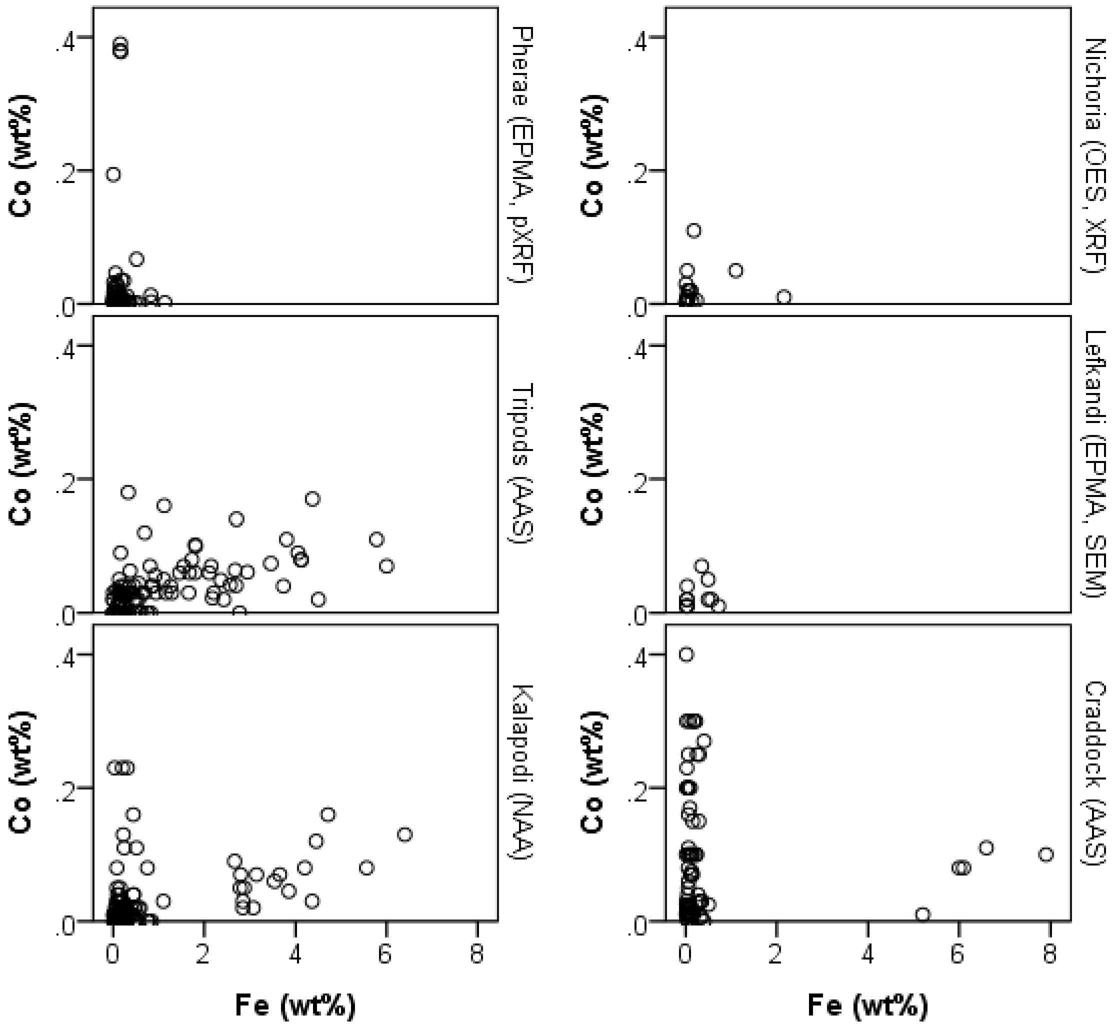


Figure 8.26. Scatterplots of iron against cobalt for the datasets mentioned in the chapter (note: only OES for Nichoria)

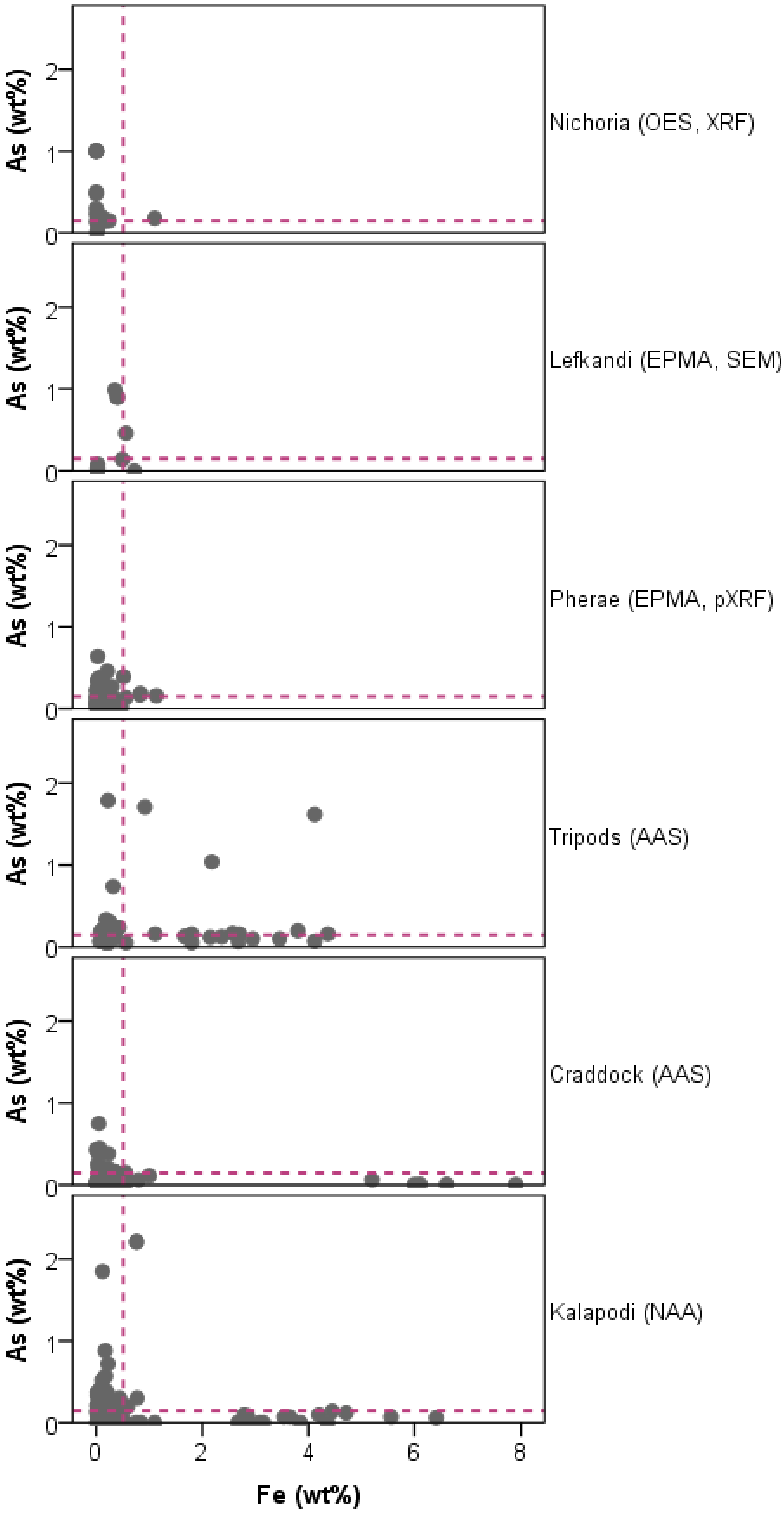


Figure 8.27. Scatterplots of iron against arsenic for the analysed assemblages; dotted lines indicate the means for each element

Chapter 9. Discussion

Discussion below explores the technology of the copper-based votive offerings of Early Iron Age Greece and their different roles that they fulfilled through their material and symbolic aspects, and aims overall to address the research aims (see Introduction). The discussion is divided into two parts which each develops the main focus of the study, namely the organisation of copper-based production in Early Iron Age Thessaly and the socio-economic role of the copper-based votive offerings in contemporary communities of ancient Pherae and Greece. Firstly, the theoretical and methodological model for the investigation of ancient technologies and object life histories, as outlined in the Introduction, has been applied to the interpretation of the Pheraean assemblage (9.1). This approach promoted the understanding of Early Iron Age copper technology and the organisation of the copper alloy objects' production in ancient Pherae and Thessaly. In addition, comparable published assemblages have been included in order to discuss metallurgical production of copper in the broader region of mainland Greece (see above Chapter 2 for a discussion of the published analyses and Chapter 8 for a synthesis of the results). Secondly, the copper-based offerings' social, economic and political role has been addressed (9.2) by considering the objects' material properties and technological attributes, their sensory aspects, any notions of their value, but also the way these objects have been employed and integrated in contemporary cult rituals (9.2.1). Finally, the broader role of these dedications in ensuring the socio-economic balance of contemporary communities via processes of communal participation and the shaping of collective memory (9.2.2) has been also explored.

9.1 Organisation of copper-based production in Early Iron Age Thessaly

The value of exploring the mode of production, standardisation, the incorporation of technological know-how and elements of tradition and innovation in past technologies in the reconstruction of the broader socio-cultural context of ancient communities, as well as the social agency of the technological practice has been much discussed amongst scholars in the humanities and the discipline of archaeology in particular (see also Introduction). Here aspects of the Early Iron Age Greek copper-based technology such as the selection of copper minerals and alloying practices have been explored, using the Pheraean assemblage as a starting point but also incorporating the published data.

Copper production and the manufacturing of finished objects is a 'sequential operation' and each of its different stages is potentially reflected to variable degrees in the finished objects (Ottaway 2001, p. 89). Hence, detailed examination of the generated data was possible to shed light on different aspects of the metallurgical cycle such as the alloying and metalworking practices as, for instance, illustrated by Ottaway (1994) (Figure 9.1). Due to the complexity of the different metallurgical stages and their potential impact on the metal produced (e.g. see Tylecote *et al.* 1977, Pernicka 1999), discussion of the artefacts' technological characteristics was able to provide more insight in primarily the metal working/smithing, alloying, and refining, while only more tentative remarks should be made concerning the procurement of raw materials and the circumstances of copper ore smelting.

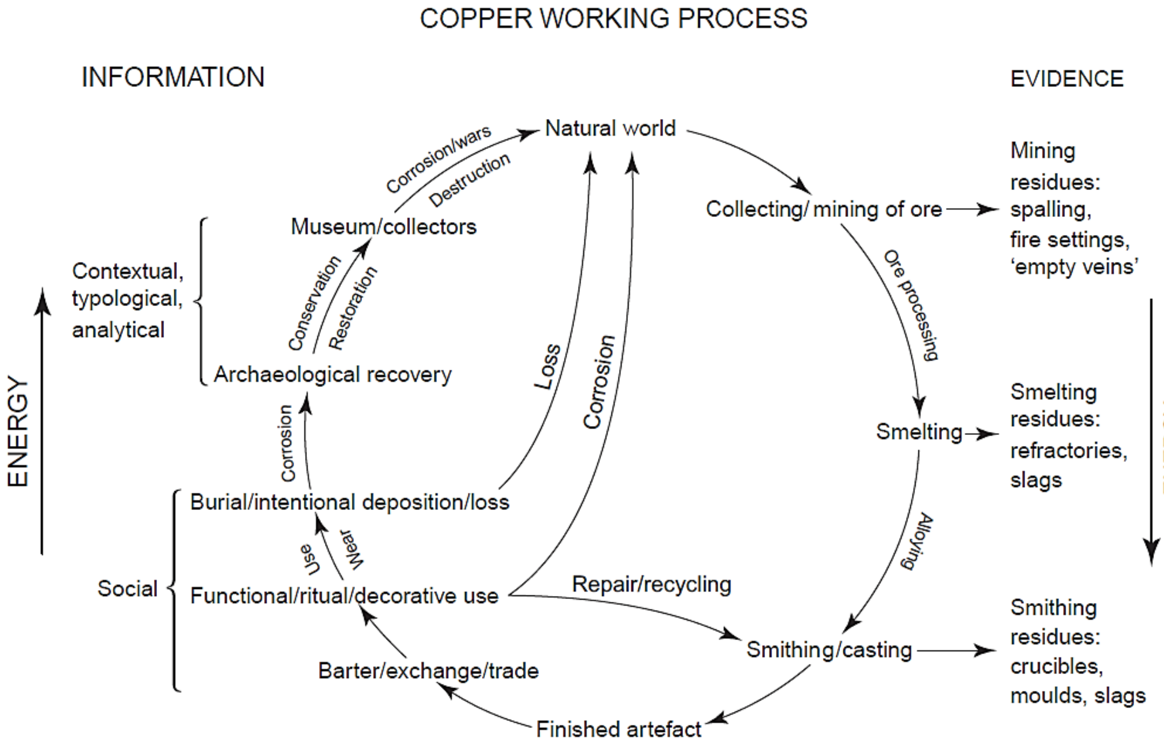


Figure 9.1. The cycle of copper production and working (after Ottaway 1994)

Evidence from the analysed assemblage has been discussed below in relation to the nature of the ores employed and their processing, the alloying and metalworking practices, and concepts of value involved in their production, circulation and deposition. Finally, the discussion focused on three themes, namely the regional character of metallurgical practice (9.1.1), the relationship between the objects macroscopic and compositional characteristics with the technological choices directed by the techno-cultural context (9.1.2), and the possibility for the existence of a value system based on the main alloying component of copper, namely tin (9.1.3).

9.1.1 Local workshops, local choices, local ores?

Analysis of the generated data from Pherae and published analyses from sites in central mainland Greece and the Peloponnese revealed certain patterns and characteristics for the various assemblages. These could possibly relate to both the particular nature of ores used and the technological choices employed during the metallurgical production in the various workshops. Below, elements of the datasets are explored along with the possibility that a certain degree of regionality existed for copper-based production during the first half of the 1st millennium BC.

9.1.1.1 Ore selection and ore processing

Evidence for the use of particular copper ores is explored to the extent that analytical data from the finished objects permit, while it is not argued that trace element concentrations alone could point to the nature of the copper ores used. Thus, the discussion focussed rather on the patterns seen in the ratios between different minor or trace elements as opposed to the absolute values which have been generated by a range of different analytical instruments. In addition, in the consideration of the minor or trace elements below, any XRF results have been excluded both from the Pherae and Nichoria assemblages, while for the latter only the OES and the NAA have been included, due to methodological concerns. Minor and trace elements have been taken as impurities possibly resulting from a combination of factors including ore contamination or the various stages of ore processing including roasting and smelting, as well as the raw copper metal refining and beneficiation steps. Despite that the source of any discrepancies cannot be pin pointed with absolute certainty, their presence has been taken as to reveal certain particularities in the metallurgical practice. Finally, these discrepancies have been used in order to investigate the similarities and/or differences within the Pheraean sample, as well as across the rest of the Early Iron Age assemblages as discussed above (see Chapter 8).

Iron and Arsenic

Two distinct patterns for iron and arsenic ratios were found amongst the different analytical assemblages, namely those from Pherae, Kalapodi, Nichoria, Lefkandi, the Delphi tripods and Craddock's analyses. As, for example, seen in Figure 8.20, three assemblages produced higher mean iron concentrations when compared to the arsenic ones, namely Kalapodi, the tripods and Craddock's analyses, whereas Pherae, Nichoria and Lefkandi assemblages provided higher arsenic contents in relation to their iron content. This variation in the iron/arsenic ratio is also well-illustrated in Figure 9.3 where a quite different pattern is seen for Pherae and Nichoria in comparison to the rest of the datasets. The Lefkandi data were too close to zero to be included in the linegraph, but they have been illustrated in the histogram of Figure 9.2. Overall, the Fe/As ratio for Pherae, Nichoria and Lefkandi showed much lower values as opposed to Delphi, Craddock and Kalapodi which showed higher arsenic levels relative to the Iron content.

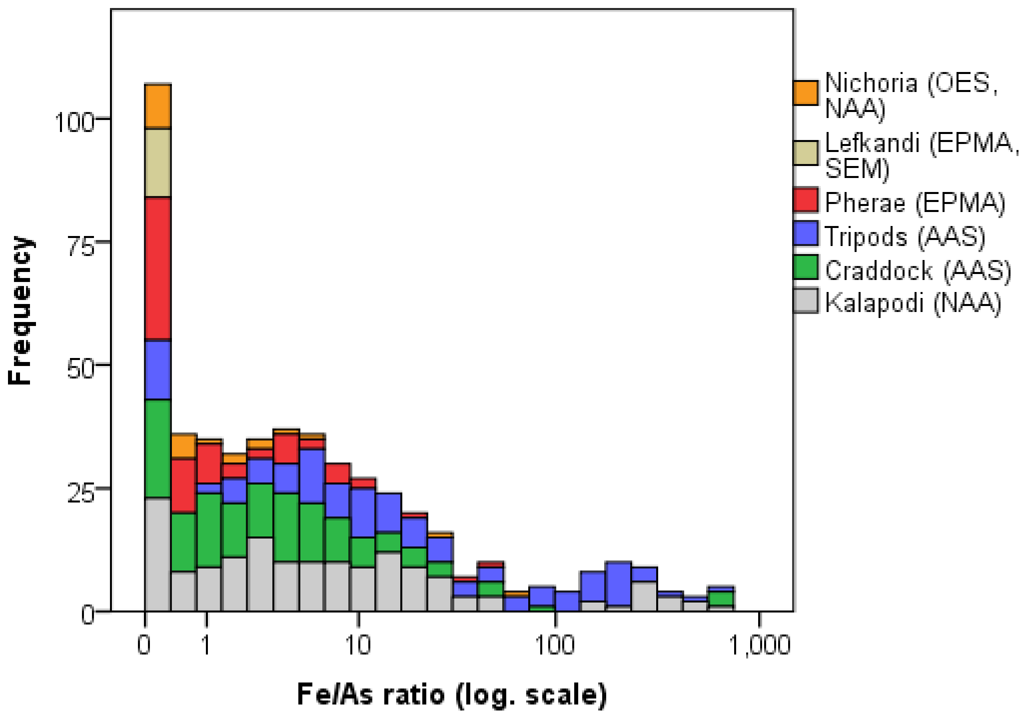


Figure 9.2. Histogram showing the iron/arsenic ratio in the published datasets and the one from Pherae in logarithmic scale (XRF results have not been included)

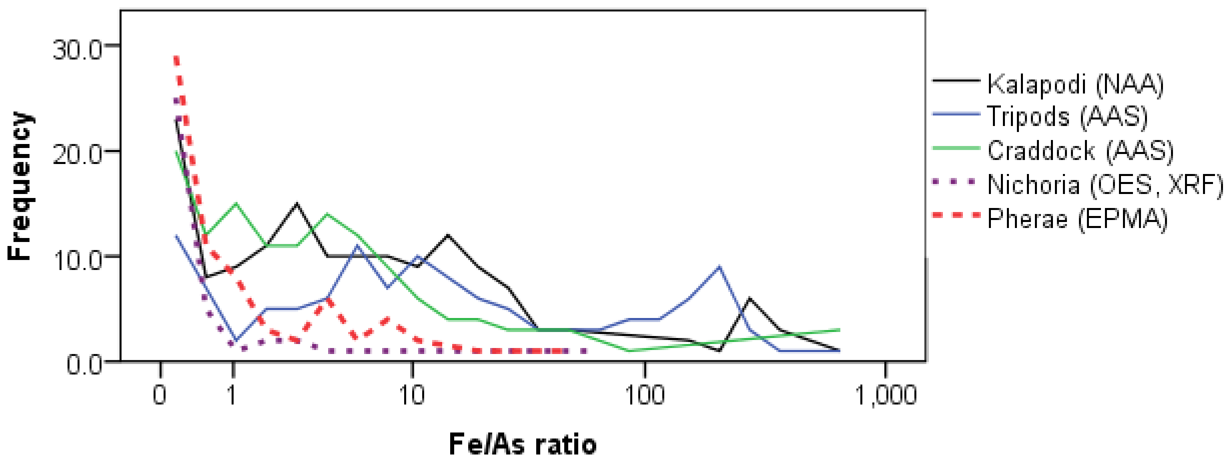


Figure 9.3. Linegraph showing the different trends in the iron/arsenic ratio in the datasets discussed in logarithmic scale; Pherae and Nichoria show a different pattern with lower values in relation to the ones seen in Kalapodi, the Delphi tripods and Craddock's analyses; Lefkandi values have been omitted since they are too low to show in the linegraph

Plotting the Fe/As ratio against the iron concentrations, not only a different pattern emerged for Pherae/Nichoria/Lefkandi and Kalapodi/tripods/Craddock, but also two different tendencies were seen for the iron-rich objects from Kalapodi and the tripods analyses. This discrepancy in the iron/arsenic ratio was well-illustrated when plotting the Fe/As ratios against the weight percent results for iron where two distinct patterns emerged, namely a low and a high arsenic groups (Figure 9.4). Values close to 0% for the low arsenic group could have been the result of element concentrations below the detection limit of the respective instruments, while it is worth noting the distinct trend line for the high arsenic group. Thus, the group of iron-rich artefacts from Kalapodi which all happen to be tripod fragments match the two patterns in Figure 9.4 for the Delphi tripods (see also Chapter 8, Figure 8.8). These tendencies found across the two datasets seem to fall into a common pattern suggesting a possible relationship between the metallurgical practices of the two sites of central Greece or even between the two communities and specific social groups which would have been involved in the operation of the cult rituals.

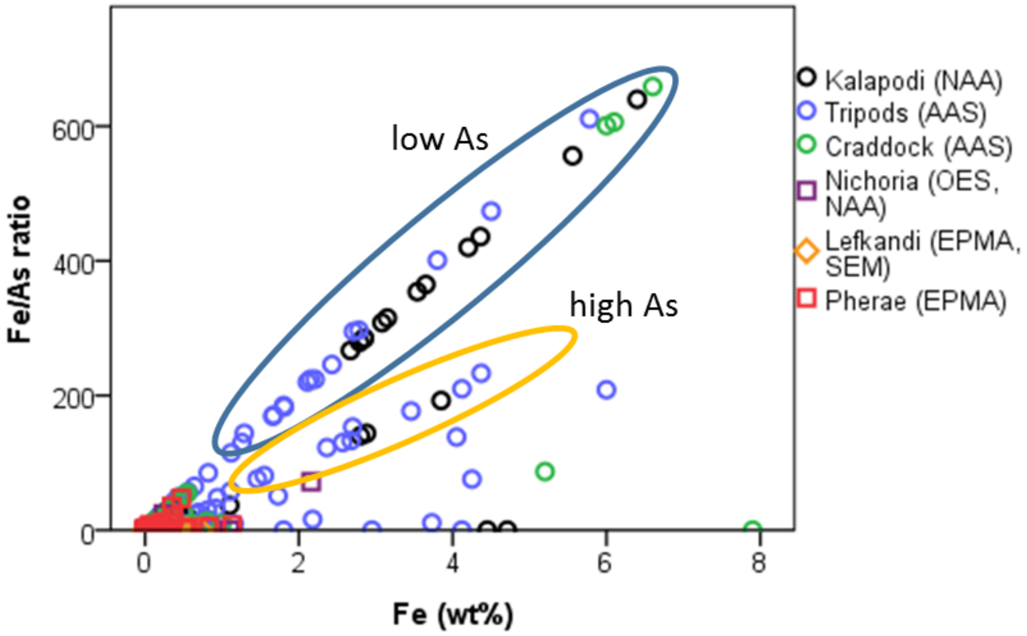


Figure 9.4. Scatterplot for the iron content against the iron/arsenic ratio for the different datasets (no XRF analyses have been included); the tripods from Delphi and Kalapodi show two distinct iron/arsenic ratio trends (note: the iron-rich objects from Kalapodi belong to the artefact type of tripods)

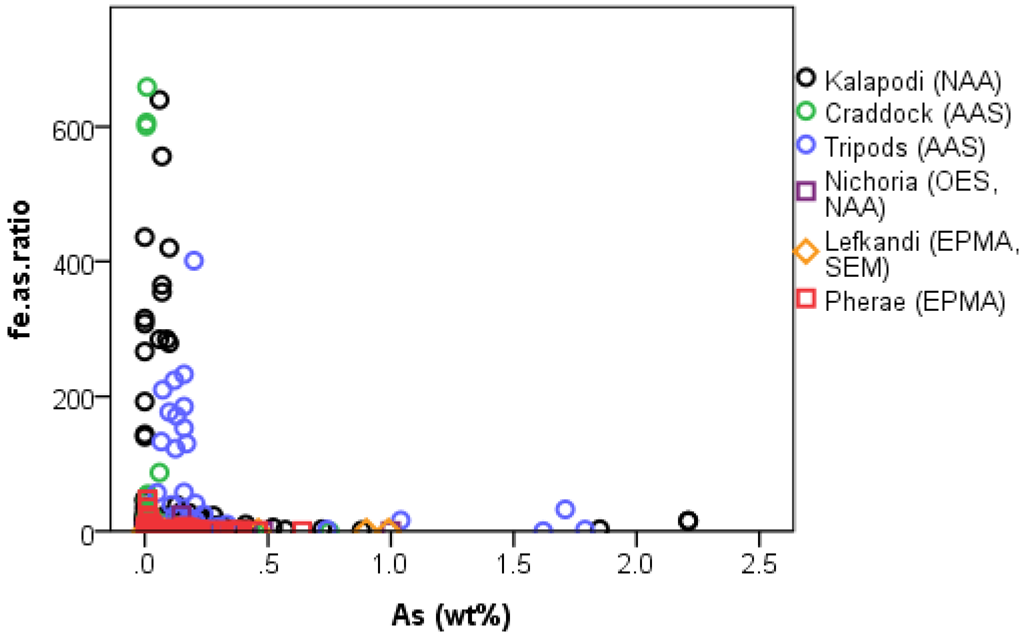
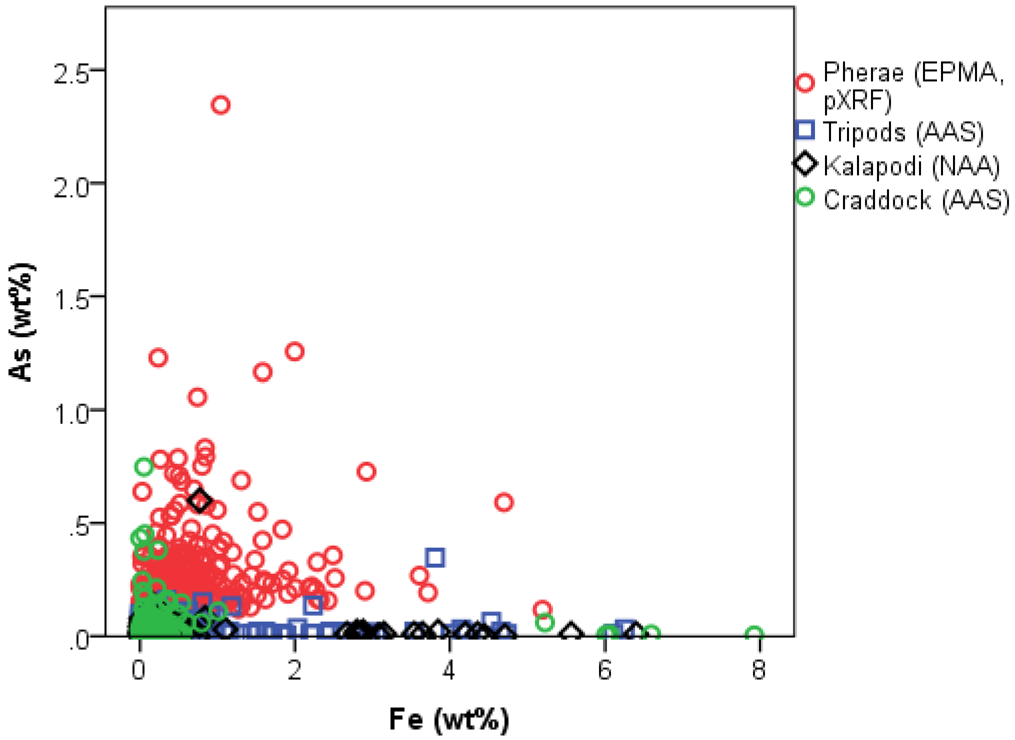


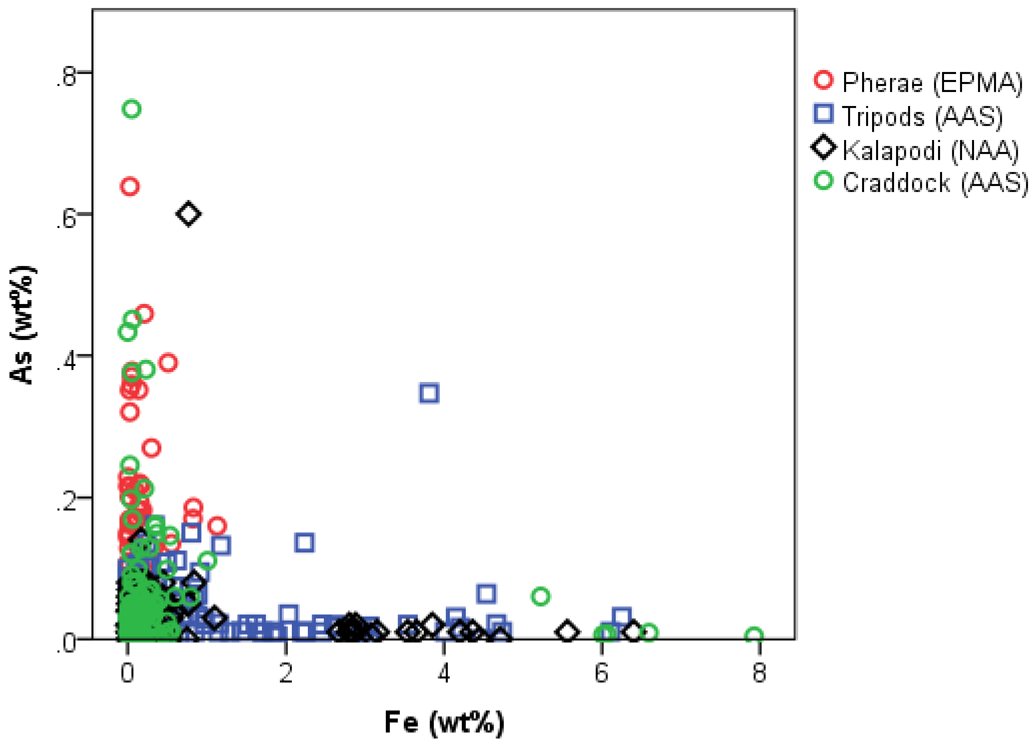
Figure 9.5. Scatterplot for the arsenic content against the iron/arsenic ratio for the different datasets (no XRF analyses have included)

If the group of tripods is excluded from the Kalapodi dataset, this seems to match the pattern of Craddock's analyses, while Pherae dataset still shows somewhat higher arsenic contents (see Figure 9.6a for both EPMA and pXRF results for Pherae and Figure 9.6b for the EPMA dataset only). Craddock's analyses showed a somewhat greater variation in the iron/arsenic ratio with few iron- or arsenic-rich objects, while the vast majority of the sample showed typically low values for both elements (Figure 9.6). This relative spread of the values seen in Craddock's analyses as opposed to the more tightly clustered rest of the datasets should be taken as a reflection of the variable geographical origin of the examined artefacts which did not derive from a single site but from several locations all over Greece.

The particularities between the assemblages of Pherae, Kalapodi and the tripods which included the largest number of analyses with 282, 154 and 115 analysed samples respectively (see also Table 8.1) were further illustrated by plotting their iron against arsenic contents as seen in Figure 9.6a & b and Figure 9.7. The larger amounts of arsenic typically present in the Pherae sample are worth consideration, along with the larger iron values for the tripods both from Delphi and Kalapodi and, finally, the typically low arsenic (<0.1% As, with a single exception) and iron (<0.1% Fe with the exception of one helmet) values for the rest of the Kalapodi sample (tripods excluded).



a)



b)

Figure 9.6. Scatterplot of iron against arsenic for the four analysed assemblage with the most artefacts analysed (A) with both the pXRF and EPMA datasets for Pherae included and (B) by excluding the pXRF dataset for Pherae

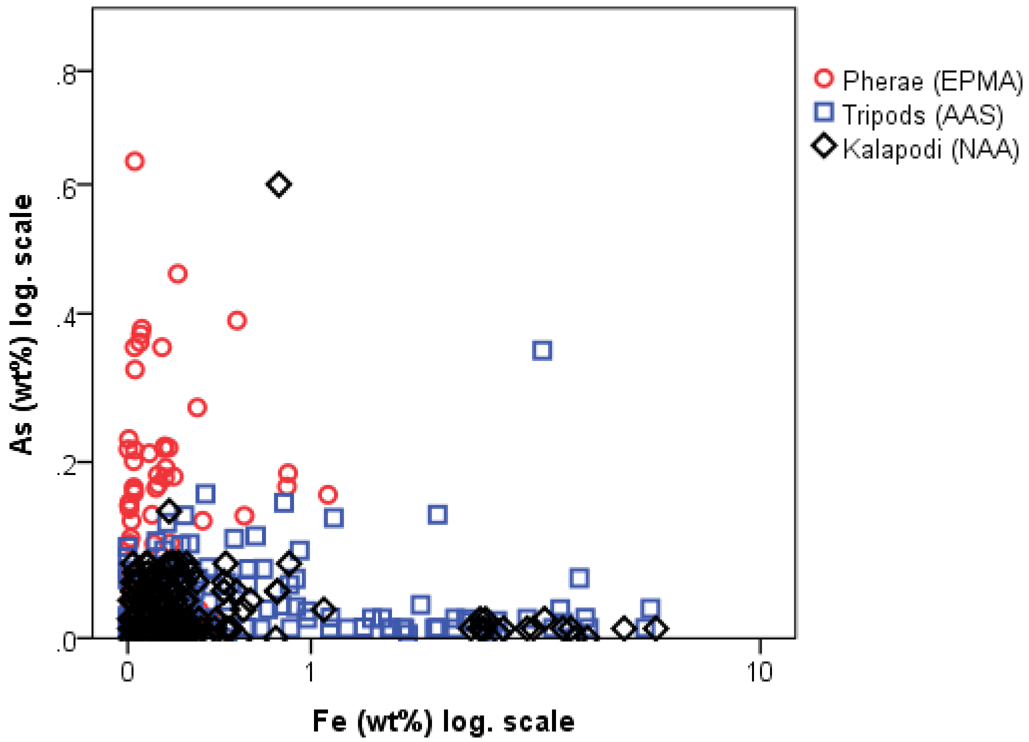


Figure 9.7. Scatterplot of iron against arsenic for Pherae, Kalapodi and the tripods in logarithmic scale in order to emphasise each assemblage's particularities; pXRF values for Pherae have not been included

Lead

Additional evidence pointing to the use of local ores by the various copper workshops of early Greece emerged from the group of Epirotic fibulae in the Pheraean sample. These fibulae showed lead at impurity levels in larger concentrations than the ones found for the Thessalian fibulae and the rest of the analysed assemblage (see also Chapter 7.3.1, Table 7.3, Figure 7.24).

It is hereby argued that certain particularities such as the arsenic to iron ratio for the different assemblages or the lead content for the Epirotic fibulae reflect the local character copper-based metallurgical processes of early Greece from ore procurement and smelting to the different stages of metalworking and finishing. It has been long argued that Greek society in the post-Mycenaean era was governed by small scale, locally organised operations as opposed to the centralised, palace-controlled administration of the Late Bronze Age (e.g. Sherratt and Sherratt 1993) which the evidence presented here seems to support further. Thus, even though evidence from the copper-based objects record recovered from the sanctuaries point to their rather large scale production, there has been here presented analytical evidence to support the regional character and the local variation of these operations.

9.1.1.2 Alloying practices

In addition to the evidence for the use of local copper mineralisations, further evidence to support the regional character of copper-based metallurgy in Early Iron Age Thessaly and Pherae was also seen in the alloying of copper with tin and lead.

9.1.1.2.1 Alloying on site at ancient Pherae

Analyses of the crucible fragment from Pherae including the tin-rich prills found in the slag matrix suggested the in situ alloying at least during the Archaic period (see also Chapter 6.4). Even though it is difficult at this stage to argue for the production of tin bronze either by the use of tin metal or cassiterite (tin oxide) (see also Chapter 2.3 on ancient tin), it is logical to extend the practice of *in situ* alloying as early as the Geometric period and the late 8th century BC when a peak for the copper-based production has been found (Figure 3.7). Most of the artefact types recovered at the Enodia sanctuary hold a strong local character and, thus, it would be reasonable to argue that local copper-based production at Pherae would have been facilitated and sustained in order to respond to local demand for both utilitarian artefacts and votive offerings. The local character of the Pheraean assemblage is also supported by the trace element concentrations found in the crucible fragment and those in the artefacts. This is, for instance, seen in the linegraph of Figure 6.24 where mean and median values for the minor and trace elements in both the artefacts and the crucible metal closely match. Larger mean and median values for lead for the objects could be explained by the fact that both binary and leaded bronze objects have been included in the design of these linegraphs.

Only nickel values appear somewhat higher for the tin bronze prill from the crucible which would have been lowered during subsequent refining and metalworking steps. Finally, the nickel and cobalt concentrations as analysed in the crucible fragment seem to complement the main cluster in the objects and the few cobalt- and nickel-rich outliers by linking the low and higher values proportionately for both of these elements (see Figure 6.20). Thus, a local production even for these outliers is suggested, while this also points to the possible variability of the copper-based objects trace elements' concentrations even within a single workshop.

9.1.1.2.2 Technological choices and regional variation in central and northern mainland Greece

The choices over the alloying processes and the additions of tin and lead provided evidence to support the regionality of the metalworking practice during the Early Iron Age in Thessaly and mainland Greece. These distinct alloy recipes which involved the additions of tin and lead have been more pronounced in the cases of the leaded bronze in the Pheraean sample, suggesting that lead was added in either low (7% tin) or medium (12% tin) bronze, but a similar pattern was also noted in the binary bronzes too (Figure 6.1). Below these patterns are tested against the artefact typology and chronology.

Looking at the artefact type distribution in the medium and tin groups, no particular correlation or pattern was noted between composition and artefact types, as the same groups of objects seem to have been produced with both alloy recipes (Figure 9.8). Only the groups of pendants and jewellery articles seem to be better represented in the medium tin group (Figure 9.9). Their tin content at around 10-12% Sn would resemble that of precious metals as opposed to the rather reddish colour of the low tin objects. Even though both these groups include a variety of artefact types, they shared common functional characteristics, namely they were meant to be displayed either as ornaments or to adorn the body.

For the dating of the diagnostic objects even though no particular pattern for the low and medium tin groups emerged, a peak for the medium tin group in the late 8th century BC was noted (dating has been based largely on Kilian's analysis and established typological sequences). Considering that most of the artefacts which were possible to date have been from the fibulae group, and looking further to the fibulae typology it becomes apparent that this discrepancy in the tin content relates primarily to the fibulae typology and not so much to their chronology. Thus, Epirotic fibulae showed mostly a low tin bronze recipe with a mean of 7% tin, as opposed to the Thessalian fibulae which mostly belonged to the medium tin group with a mean of 11% tin (Figure 9.10).

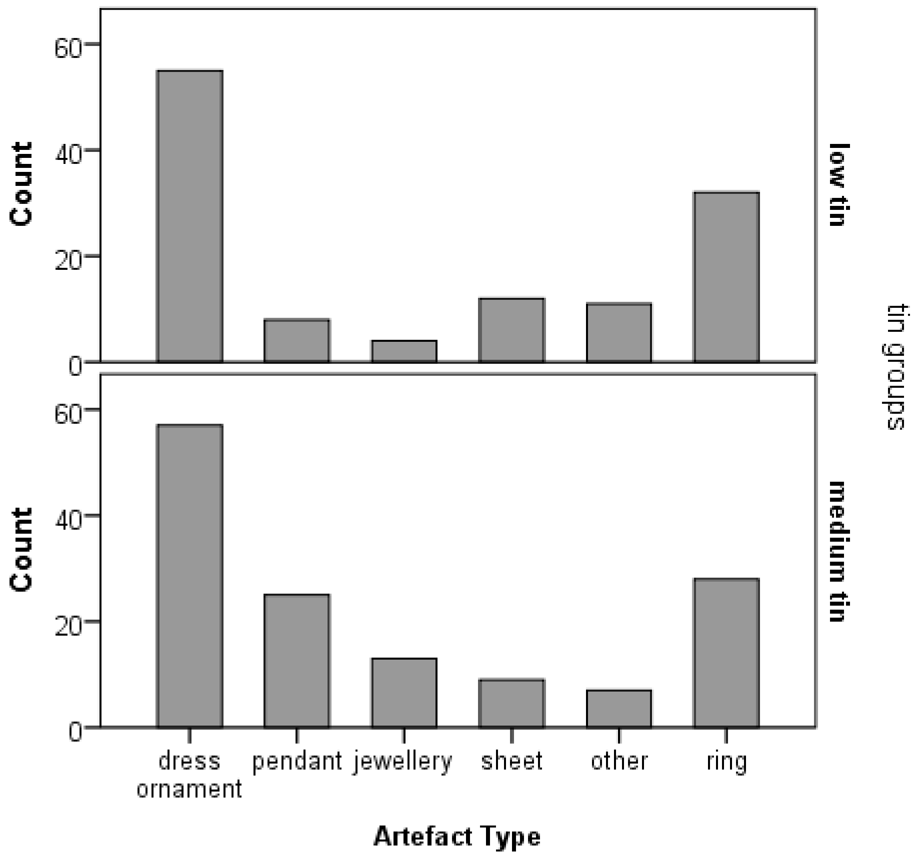


Figure 9.8. Barchart showing the frequency of the different artefact types in the low and medium tin groups; no particular distinction is noted

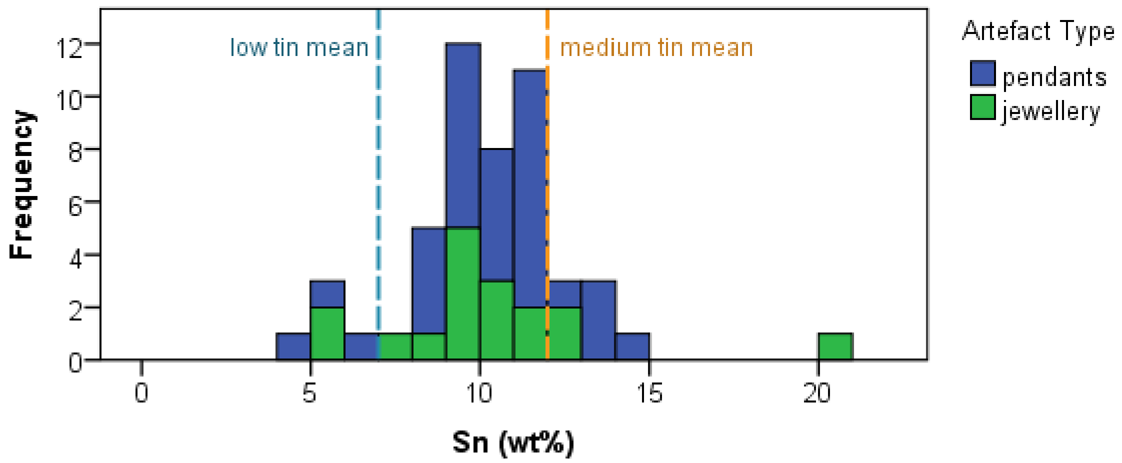


Figure 9.9. Histograms showing the tin distribution in the groups of the pendants and the jewellery articles; blue dotted line for low tin group mean, and orange dotted line for medium tin mean values

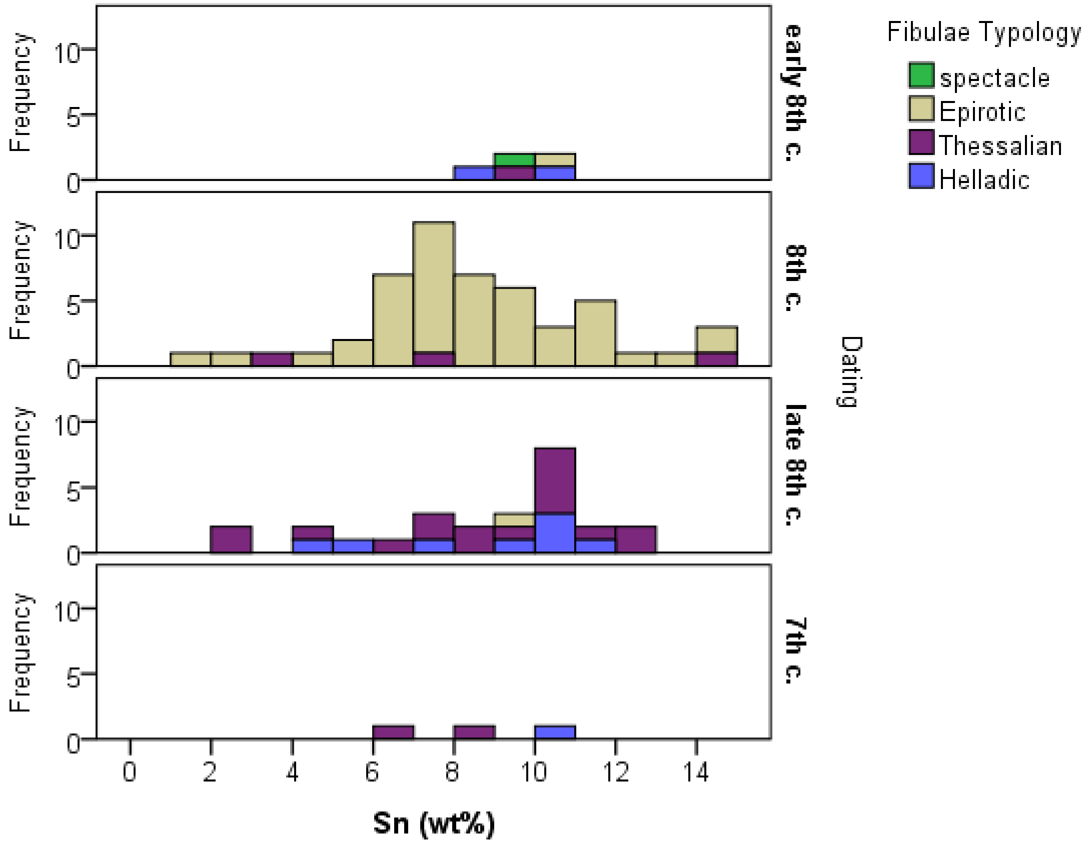


Figure 9.10. Histogram of tin distribution for the fibulae in the sample dated to the 8th and 7th centuries BC

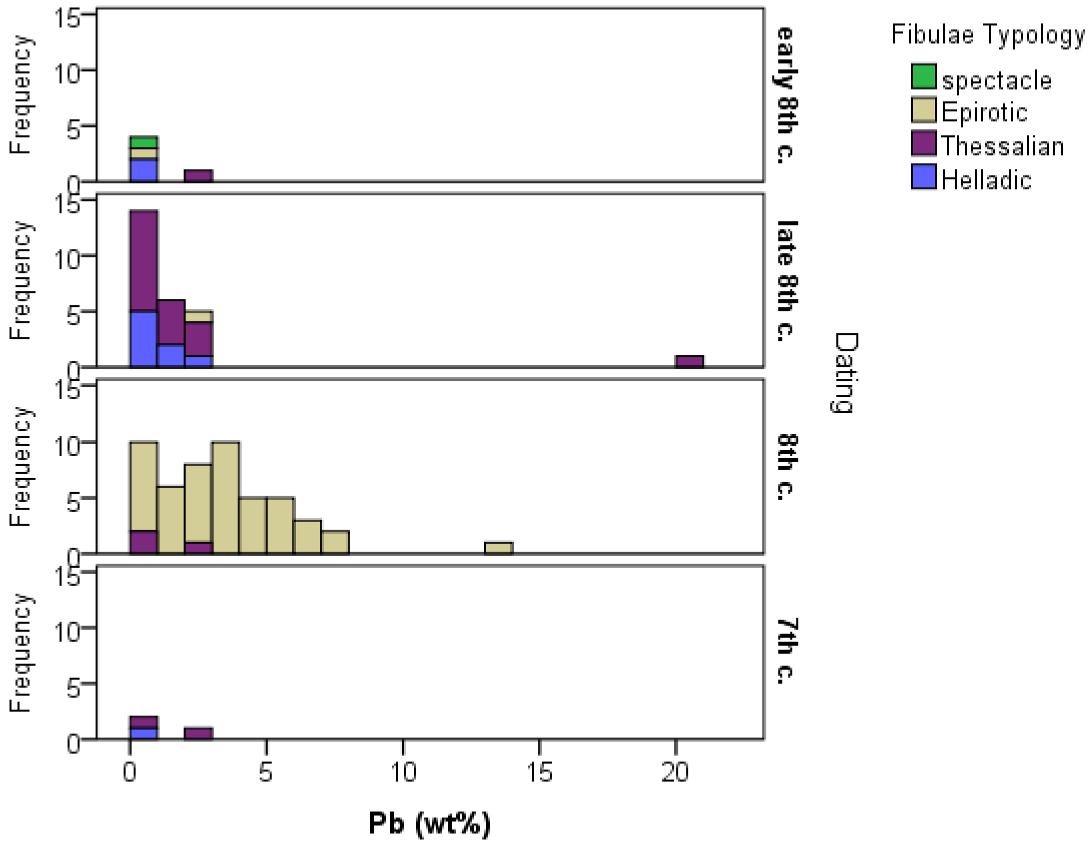


Figure 9.11. Histogram of lead distribution for the artefacts in the sample dated to the 8th and 7th centuries BC

Furthermore, the groups of Epirotic and Thessalian fibulae showed quite characteristic patterns not only in their tin contents, but the lead too. The lead concentrations for both fibulae groups suggest that the element was present as an impurity most probably from ore contamination. Thus, in the Thessalian fibulae the lead content is quite low, typically below 1%, whereas in the group of the Epirotic lead is regularly found at several percent (Figure 9.11). Consequently, the pattern which emerges for the two fibulae groups suggests that not only different copper ores were employed for their production, but also this raw copper was alloyed with tin in different and quite distinct alloy recipes reflecting different technological traditions at least for Early Iron Age Thessaly and Epirus.

However, even by excluding the group of the non-Thessalian fibulae, namely the Epirotic, Helladic and Phrygian fibulae in the sample, the pattern of a bimodal distribution for the tin content in the leaded bronzes from Pherae is still present (Figure 9.12). Meanwhile, a normal distribution curve was found for the binary tin bronze alloys. This discrepancy could suggest that the addition of lead in amounts larger than 4% Pb and, hence, the production of a ternary alloy recipe acquired different technological characteristics as opposed to those of binary bronze. Finally, the above evidence could suggest that the two alloys were considered and treated as different from the Early Iron Age Thessalian metalworkers involved in the production of the various copper-based artefacts.

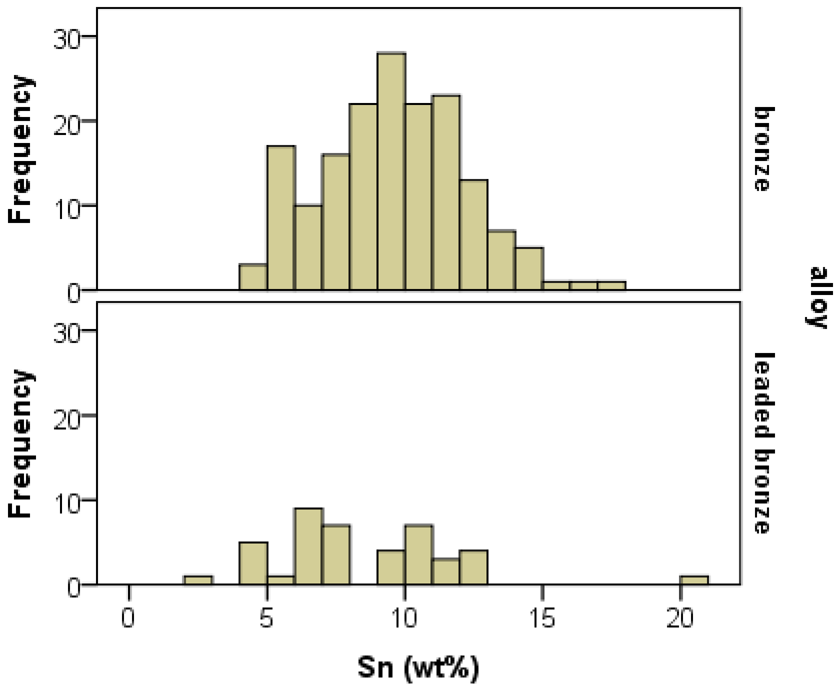


Figure 9.12. Histograms for the tin distribution in the Pheraean sample by excluding the non-Thessalian typology fibulae, namely the Epirotic and the Phrygian

9.1.1.2.3 Organisation of copper-based production at Pherae

Examination of the trace and minor element concentrations in the low and medium tin groups in the objects with a local/Thessalian origin as defined by their typology showed certain particularities to suggest the distinct metallurgical technologies (apart from the bimodal addition of tin in the leaded bronze, Figure 9.12). Exploration of the minor and trace elements in the low and medium tin groups by excluding the four Epirotic fibulae in the EPMA dataset showed no particular discrepancies. This is further illustrated in the linegraphs for the lead, arsenic, cobalt or sulphur concentration according to the two tin recipes (Figure 9.13). Only in the arsenic and cobalt concentrations some minor differences were noted, but these were not sufficient to support at present the use of different raw materials.

Organisation of the Thessalian copper-based production in the 8th and 7th centuries BC showed evidence for a quite stable supply of raw copper, as well as of tin, while lead was only occasionally added in tin bronze (see this chapter below 9.1.2). The bimodal distribution for the tin content of the Thessalian artefacts did not provide further evidence for the use of different copper minerals. Meanwhile, at the current stage of research it is difficult to argue for a synchronic or diachronic operation of different workshops at ancient Pherae or in the broader region of the Thessalian plain. Nonetheless, the preference for particular alloy recipes when it came to the alloying of copper suggests that close control took place over the addition of both tin and lead, as the latter was typically added on either 6-7% or 11-12% tin bronze, whereas for binary bronze mean tin values of 9% were preferred (Figure 9.12).

To sum up, it seems quite likely that different recipes were employed by using the same copper ores. And, thus, it is possible that the use of these distinct recipes depended either on cultural factors as, for example, in the case of a synchronic use of both copper alloy recipes or possibly on the supply of tin and its availability in different chronological periods in the Thessalian plain in the case of the alloys' preference over different periods.

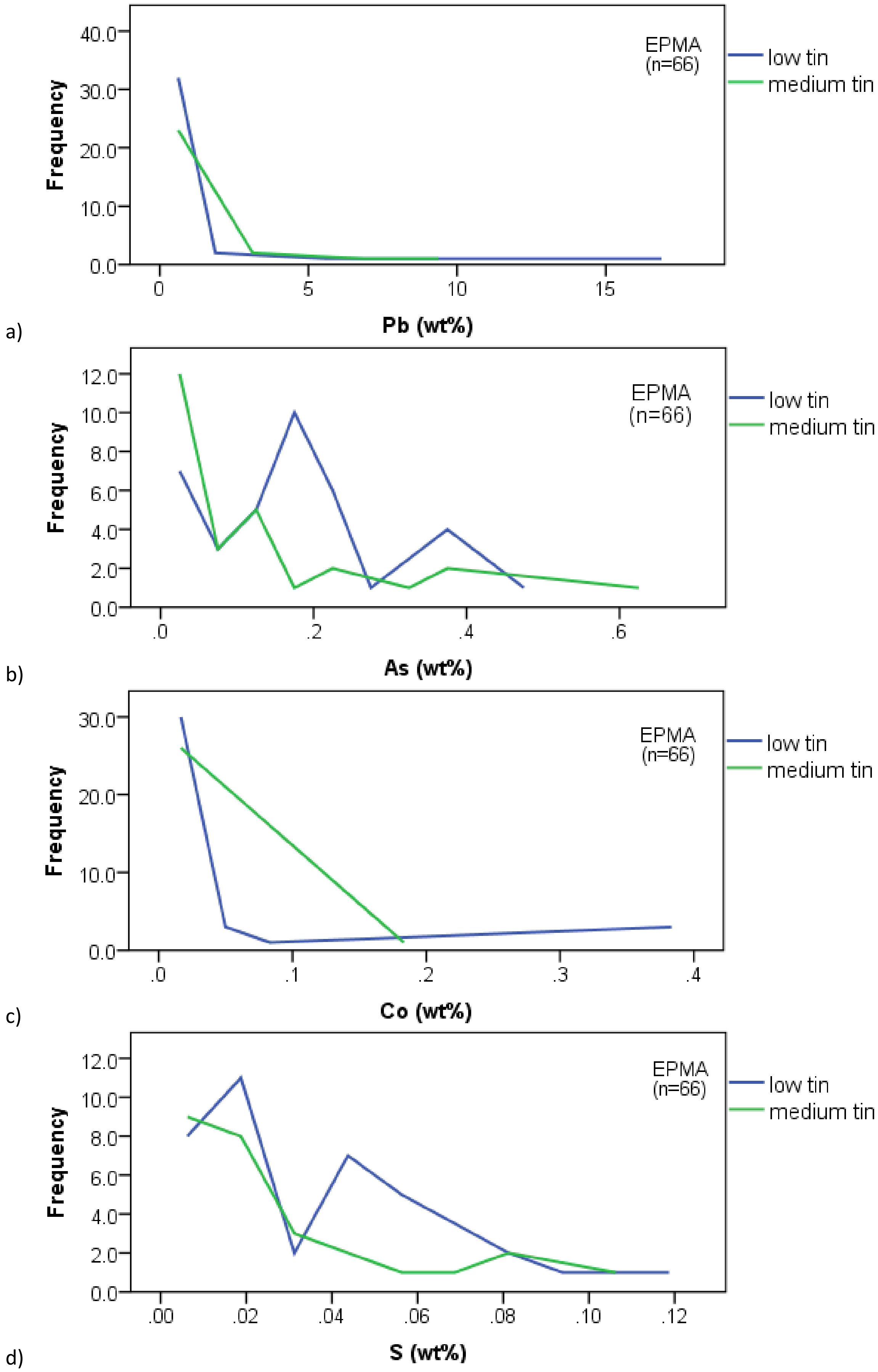


Figure 9.13. Linegraphs for the lead, arsenic, cobalt and sulphur concentrations in the objects with seemingly Thessalian origin – Epirotic fibulae have been excluded (EPMA, n=66)

9.1.2 Specialisation and standardisation of copper-based production

Below, aspects of specialisation and standardisation of the copper-based technology at Pherae are discussed. The above topics have most often been considered during the investigation of past technologies, while their definitions have been often discussed, negotiated and revisited (e.g. see Hruby *et al.* 2007). Nonetheless, a concise and inclusive definition for technological specialisation could be that such as outlined by Ottaway (2001, p. 89, after Mark Edmonds), namely 'the consistent production of things by some people for others'. Meanwhile, craft specialisation may potentially entail a range of production modes from small to large scale which may 'reflect relative labour investment, skill and standardization [… whose] analyses allows us to identify general trends in the organization of production' (Costin and Hagstrum 1995, pp. 619–620). Hence, for the purposes of the present study, the objects' typology and other morphological characteristics such as their size and function, along with their technical aspects such as their metalworking and chemical compositions have been taken into consideration in order to explore aspects of the copper-based production's degree of specialisation. For instance, a particular artefact type being manufactured with a specific alloy recipe has been hereby taken as an indication of a high degree of specialisation of the metallurgical practice, whereas an artefact type found in various metals and alloys would be suggestive of the production of this object group most probably by a larger number of metalworkers and/or workshops and even during subsequent chronological periods.

9.1.2.1 Labour investment: the matter and the process

Starting with the investigation of the effort put by the metalworkers in the production of the various artefacts in the metallographically analysed sample (n=70), a relationship between the alloy recipe employed and the labour invested was found which is indicative of the standardisation of the metallurgical practice and the degree of specialisation. A correlation between the tin content in copper and the metalworking intensity was visible. The above has been illustrated, for instance, in Figures 7.14b and 7.16 where mean tin values for the objects with traces of mild metalworking to those with traces of intense metalworking have been increasing from 7% to 10% with respective modes at 5%, 9% and 11% tin (Table 7.1). In addition, the distribution curves for the different metalworking groups have been better defined in the intensively worked groups (C/D), while the scatter of tin values is larger for mild metalworking or casting (A/B) (see Figure 7.16). This correlation between effort investment and tin content is quite characteristically illustrated in the group of the metal sheets which due to their shape have all been hammered into shape but with variable intensity (see also below this Chapter 9.1.3). Thus, in Figure 7.44 the tin content has been proportionate to the effort put during the hammering of the various metal sheets. No definite conclusions can be drawn for cast artefacts since this group comprises of just three samples microscopically examined. However, it is worth noting that rather variable tin and lead concentrations have been found in the castings as opposed to the more intensively worked objects (Figure 7.14a & b). Finally, the intensively worked group comprised of tin bronze while leaded bronze was more frequently employed when casting or mild metalworking took place (Figure 7.18). Overall, such metalworking choices would have been also dictated by the tin content itself which would have increased the alloys' hardness and would, thus, require repeated and more intense metalworking. These choices could have been culturally led, but they would have also been a necessity for the shaping of harder, tin-rich alloys.

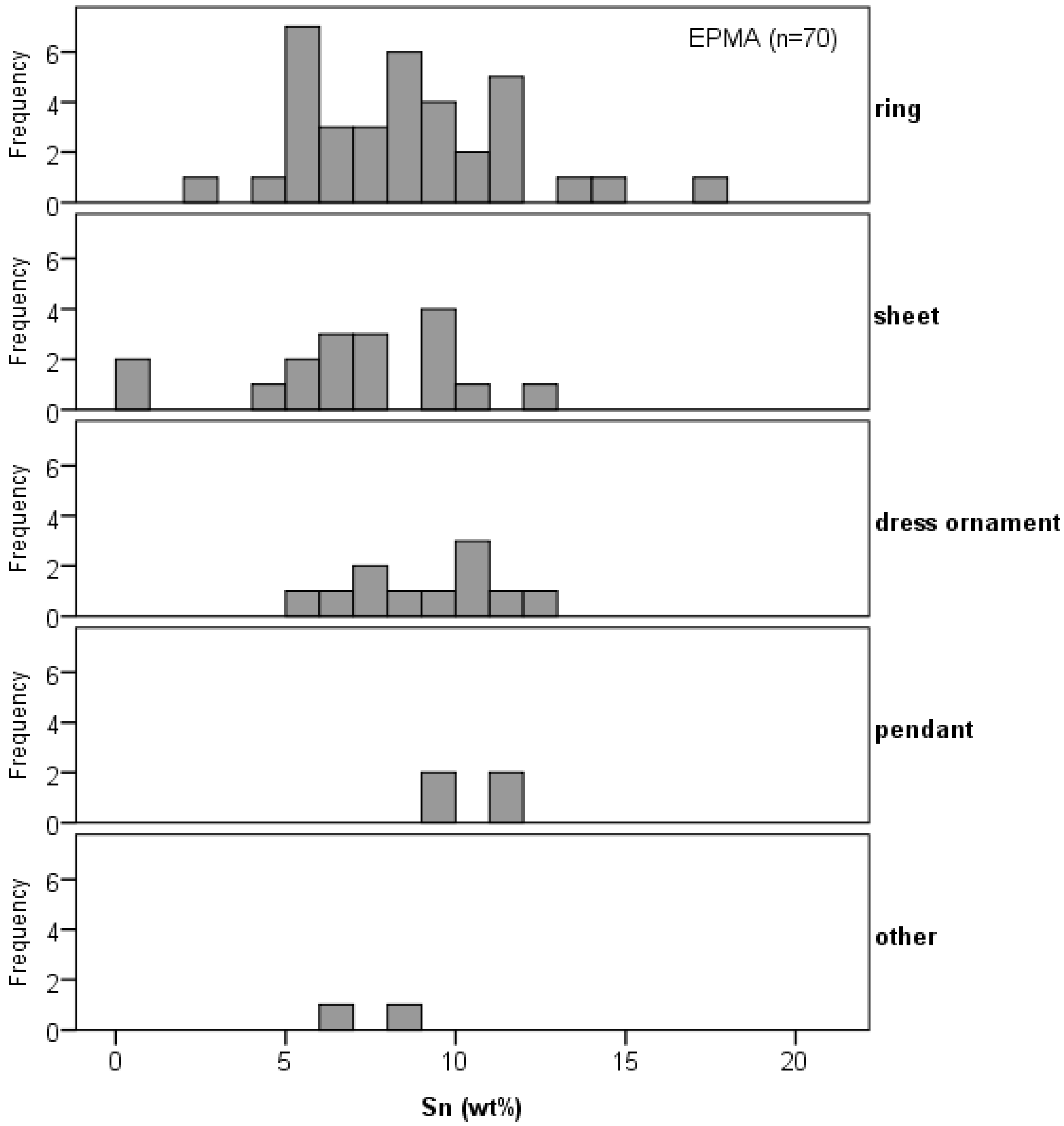


Figure 9.14. Histograms showing the tin distribution in the different artefact types in the EPMA dataset (n=70)

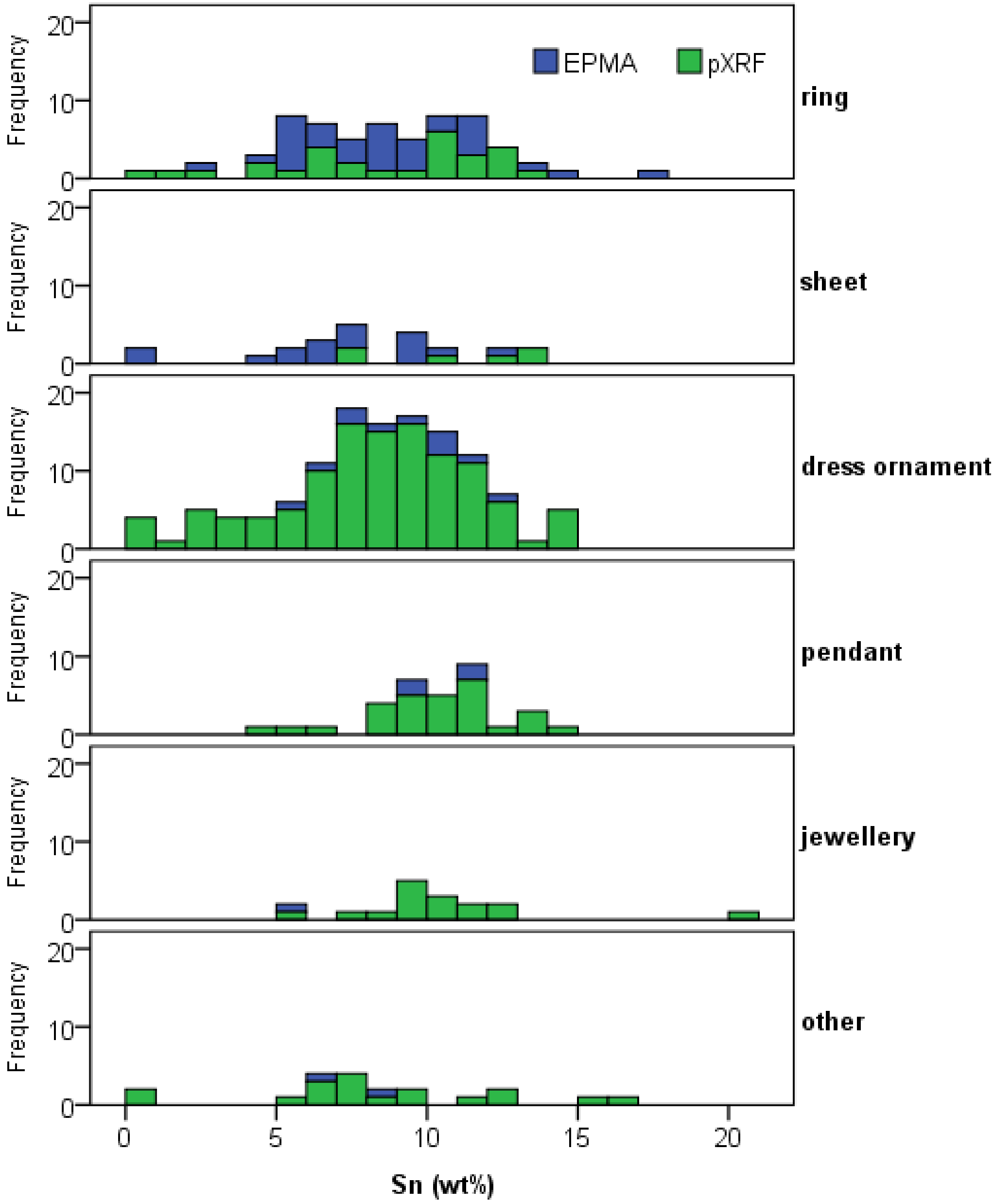


Figure 9.15. Histograms showing the tin distribution in the various artefact groups in the pXRF and EPMA datasets (n=282)

9.1.2.2 Type and 'logos': shape and choice

In addition to the aforementioned relationship between alloy recipes and metalworking treatments, certain technological choices seem to have taken place in regard to the artefacts' typology as specific object types and subtypes provided evidence for the use of particular alloy recipes. The above pattern is, for example, visible in the histograms of the tin distribution for the various artefact types in the sample as illustrated in Figures 9.14 and 9.15 where bell-curve normal distribution for the tin content were found for most of the artefact groups such as the dress ornaments or the pendants. However, certain artefact groups showed variable tin contents such as the rings with 3-17% tin contents (Figure 9.14).

In order to accommodate the varied typology in the rings' group, these have been classified in five different types, four of which have been further subdivided into two subgroups (see also Appendix I). An interesting pattern emerged where often, though not exclusively, distinct compositions were found for subdivisions of the same ring type. For instance, the above pattern was well-illustrated in the ring Types IVa and b, and Va and b, where the b subtype showed a quite distinct alloy recipe by comparison to the 'a' variation with either lower or higher tin content (Figure 7.35).

The Type I rings, the simplest amongst this artefact group, showed a variety of both metalworking treatments and alloy recipes suggesting that no particular choices were taken during their manufacturing. In fact, this ring type (Type I) would have been an artefact quite easy to shape simply by folding a round cross-section copper or copper-alloy wire (Figure 7.32a). Hence, this rather unsophisticated ring type could have potentially been produced by a range of metalworkers, in various regional workshops and by adopting a wide range of technological choices over long periods. Meanwhile, the above picture does not seem to emerge in regard to more elaborate ring types or, in fact, other elaborate object groups such as the bird pendants or the fibulae. Thus, particular alloy recipes already discussed for the fibulae groups (as also discussed in Chapter 7.3.1, Figure 7.24) further indicate that specialisation of copper technology took place in regard to the artefact types.

9.1.2.3 Size matters

Finally, the objects' size and, in turn, their intended function seemed to have had an impact on their technology. This has been well-illustrated in the group of oversized Thessalian fibulae which with bows of 10 cm and original weight approximately 400-500 gr would have been impossible to wear as dress ornaments (Figure 7.29). Even though a 10-15 cm bronze casting would not have been particularly big or difficult to cast during the Greek Early Iron Age, particularly taking into consideration the large tripods with animal attachments or the Geometric horse figurines, these fibulae's dimensions strike as quite large as they are two or often three times the typical size of the Thessalian fibulae. In addition, the oversized fibulae were distinguished on the basis of their high lead content between 10% and 21% (Figure 7.28) as well as their bows which have been manufactured with the lost-wax technique as suggested by remnants of the ceramic core retained in the bow globules (Figure 9.16).

This relationship between size, function, alloy recipe and metalworking shows distinct control in the copper-based production in Early Iron Age Thessaly and Pherae. Contemporary technological choices were closely guided by a number of cultural factors which reflect the degree of the technological knowledge of the metalworkers such as the benefit of the addition of lead towards the fluidity and castability of bronze which would have facilitated the manufacturing of these castings and the use of the lost-wax technique for economy of resources.

Figure 9.16. Detail of the oversized Thessalian fibula M 226.1 with hollow globules on the bow shaped during the lost-wax technique and after the clay core was removed

Overall, aspects of craft specialisation and standardisation discussed above are taken as indications of a well-organised technological practice that was well-embedded into contemporary society, namely a practice with a long tradition which was orchestrated by experienced smiths. Furthermore, even though the dating or the actual site of manufacturing for the different artefacts from the Enodia sanctuary cannot be narrowly defined, it is suggested that smiths who facilitated metallurgical copper-based production were also in a position to transmit existing knowledge in subsequent generations. The latter, in turn, resulted in a rather long-standing tradition which dictated certain technological choices such as the laborious metalworking of tin-rich bronze, the use of specific alloy recipes for particular artefacts types or the use of local ores by regional workshops.

9.1.3 An Early Iron Age value system

Below, notions around the social and economic value of the metals involved in the various production stages of the copper-based objects are discussed. The various factors which determine the value of objects and/or materials are regarded as interwoven to a certain degree and not as separate such as, for example, discussed by Ottaway (2001, p. 89) who refers to the 'social *or* economic value' of commodities (my emphasis). Hence, it is hereby argued that the economic value of metal artefacts itself is also determined by social factors, while the beliefs shared by a group of the consumers and manufacturers would have also had an impact on the end products. However, these value determining factors do not necessarily have clear-cut boundaries as customers would have to choose from the available choices, but also these offered products would have been produced having in mind the customers' preferences.

On the one hand, public demand of Early Iron Age Thessaly would have to be satisfied by the available metals, namely copper, tin and lead, and their alloys in the case of non-ferrous metallurgy; but, on the other, the particular choices involved in the production of the copper-based artefacts along with the actual amount of tin or lead added in copper or the choice for unalloyed copper would have been largely relied upon social factors too which would in turn render these artefacts valuable. Contemporary beliefs on what was considered proper and/or aesthetically attractive by both humans and gods, since the latter would have often been the recipients of these products, would have shaped the outcome of metallurgical production. In the present exploration, as indicators of value according to popular demand have been considered (a) the labour investment on the part of the smiths, (b) the frequency of the metal(s)/alloys(s) occurrence and (c) the proportion of the alloying elements to copper.

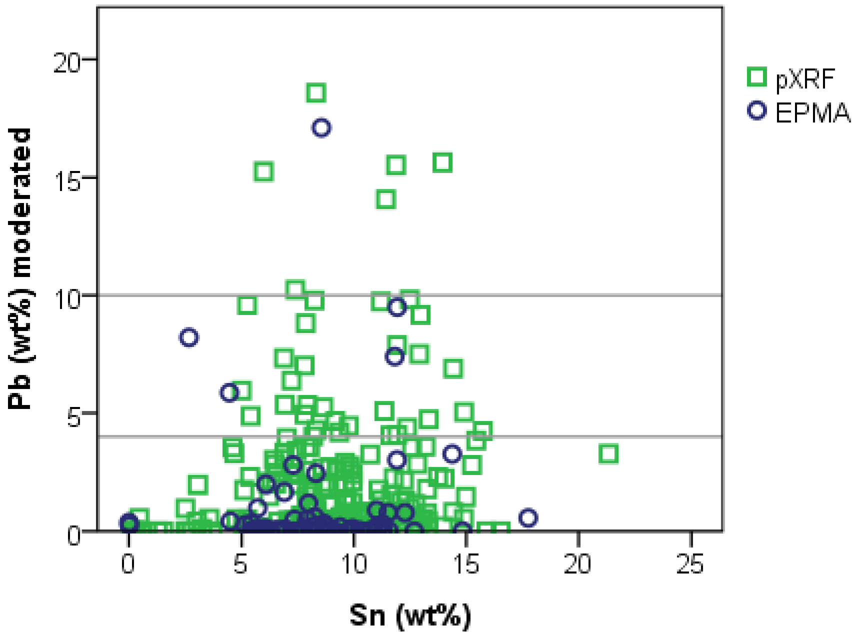


Figure 9.17. Scatterplot of tin against lead for the EPMA and pXRF analyses of the Pherae sample; lead content as analysed with the pXRF has been moderated by -30% in order to make up for the instrumental error (see Chapter 3, Figure 3.15); grey lines at 4% and 10% lead

The proportion of alloyed copper as opposed to unalloyed one which form only 6% of the Pheraean sample is striking. In addition, half of these objects contained particularly low tin concentrations below 1% Sn (see also Tables 4.6 & 4.7). The prevalence of tin bronze is quickly noted covering 72% of the sample or 79% when the lead content as analysed with pXRF is moderated by -30% in order to make up for the instrumental error (see also Chapter 3.2.3) (Figure 9.18). Similarly, leaded bronze objects constitute 21% or 15% of the sample before and after moderation of pXRF results respectively. In both the pXRF and the EPMA datasets only very few lead-rich objects have been analysed (see Figure 4.1a & b), while a quite distinct lead-rich group of six objects seems to emerge with lead contents between

14% and 19% lead even after the moderation of pXRF results (five analysed objects with pXRF and one with EPMA) (Figure 9.17). Consequently, the largest compositional group by far, as also seen in Figure 9.18, is that of binary bronze often with lead impurities in variable concentrations. This prevalence of tin bronze over other alloys that would have been available during the Greek Early Iron Age also marks the popularity of tin bronze and its added value amongst contemporary communities.

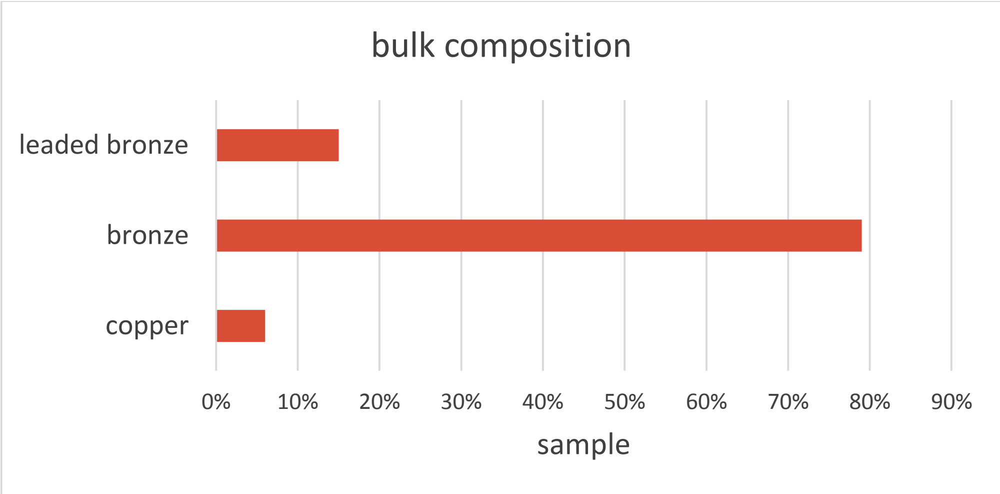


Figure 9.18. Barchart showing unalloyed copper and copper alloy distribution in the analysed sample (n=282, EPMA and pXRF); leaded bronze has been calculated on the basis of moderated pXRF results

This marked preference for tin bronze should be taken as a response to the availability of resources and technological knowledge, as well as to the long-standing tradition for the use of tin as the standard choice when it came to alloying copper going back already several centuries and in the Bronze Age. Nonetheless, in this metallurgical choice and in light of the relative absence of unalloyed copper objects there stands the possibility for the cultural context of Early Iron Age Greece to have shaped metallurgical production by providing an increased demand for this copper alloy. Taking into consideration that perfectly usable objects could have been potentially made from unalloyed copper (Ottaway 2001, p. 97), this particular choice for binary tin bronze raises questions in relation to its physical and/or sensory properties and the impact these had on contemporary Thessalian society. For example, it could have been the colour of a 10% tin bronze which seemed particularly attractive or it could have been the knowledge of the tin addition such as marked by the colour of the artefacts which made them valuable and desirable. Furthermore, the correlation between the tin content and metalworking intensity (Figure 9.18) would have potentially added further to the objects' value and the way they were perceived by contemporary Thessalian communities. Finally, it is worth highlighting that the above correlation showed the willingness, but also the need to invest time, effort, and resources in tin-rich alloys due to their increased hardness.

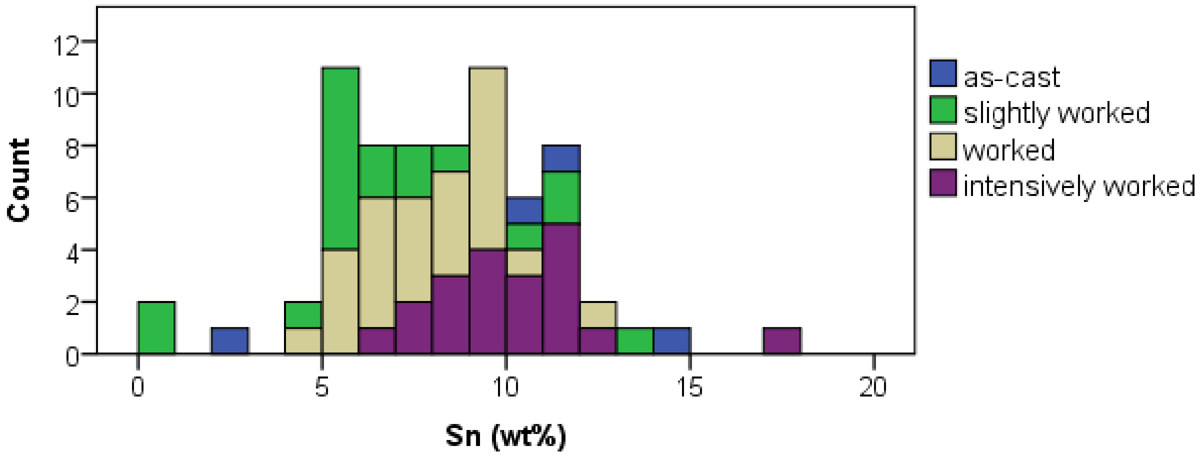


Figure 9.19. Barchart showing the tin distribution in the EPMA dataset according to the metalworking of the Pherae samples as examined during metallography (n=70)

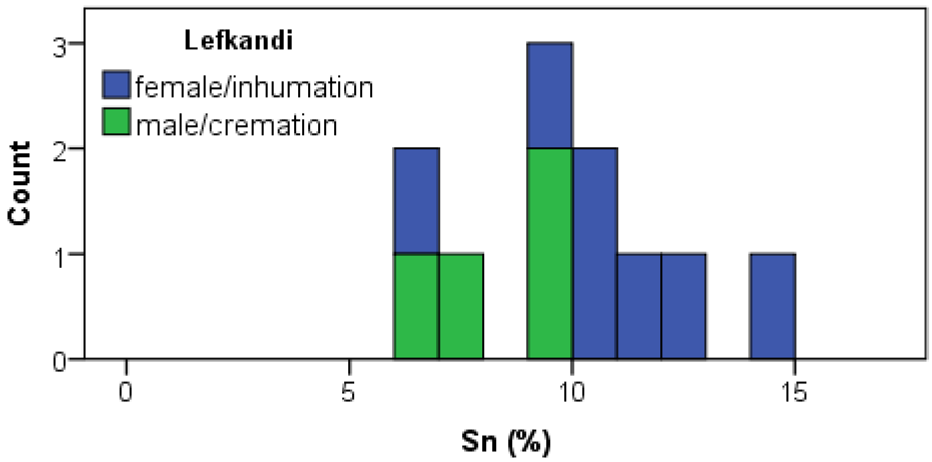


Figure 9.20. Barchart showing the tin distribution in the Lefkandi sample (n=11) according to gender and burial type (EPMA and SEM-EDS results)

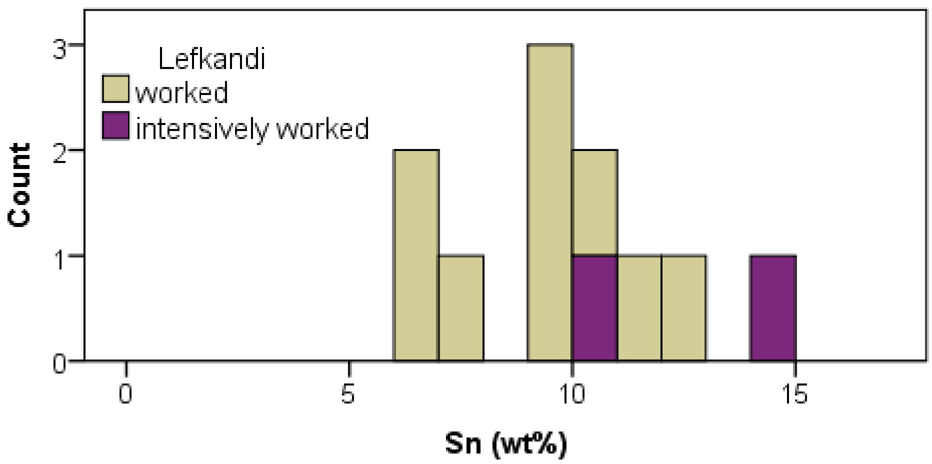


Figure 9.21. Barchart showing the tin distribution in the Lefkandi sample (EPMA, SEM-EDS) according to metalworking technique as defined during metallography

However, this correlation between labour investment (value) and tin amount (quantity) should not be taken as universal. For instance, there are indications to suggest that for the Early Iron Age community at Lefkandi, gender seems to have been an important value determinant during the metallurgical and alloying processes than the mere quantity of tin in the copper alloy. Copper-based burial offerings from the Toumba cemetery have that bronze with <10% tin was typically deposited in male, warrior cremations, whereas typically higher tin contents between 10% and 15% were found in contemporary female burials (Figure 9.20). Meanwhile, no clear correlation has been found between the tin contents and metalworking intensity (Figure 9.21), even though a larger sample from the cemetery would contribute further in the above discussion as the assemblage discussed here consisted only of eleven artefacts.

Lefkandi was a community with signs of a well-stratified society where men and women of its ruling class were treated distinctly such as seen in the particular burial rites performed, namely cremation and inhumation respectively. The nature of the grave offerings in male and female burials also showed a very distinct character which seems to emphasise quite distinct gender roles for males and females respectively. In a society for which the objectification of women has been suggested, namely their treatement as a warrior's extended identity (Morris 1986, Cohen 1995), it is difficult to visualise the warriors receiving cheaper, i.e. low-tin, burial offerings than their wives. Hence, it must have been additional attributes of the copper alloys being valued such as, for example, the alloys' colour and not necessarily their tin content. Consequently, the marked preference of tin bronze over copper or leaded bronze seen in EIA Pherae invites consideration of social and aesthetic factors playing an important role too in copper-based production and depositional activity at the sanctuary of Enodia.

9.2 Material that matters: the social and economic role of metal in the divine realm

Below the impact of the bronze votive offerings on the different parties involved in the process of their sacrificial deposition, namely the devotees, the sanctuaries' administration and their visitors, as well as the social body as a whole is examined in more detail. Archaeological research has often dealt with the record of past ritual practices and the interpretation of their material remnants including the metal votive offerings (e.g. Trevelyan 2004, Uribe Villegas and Martinón-Torres 2012). Analysis of the Early Iron Age three dimensional, votive, cast bronze, anthropomorphic figurines by Langdon (1999) has, for example, offered an insight into the social developments of contemporary Greek communities. Langdon provided evidence for the 'co-existence of equality, but also hierarchy' in early Greek society, as well as the prevalence of a male presence as seen in the male figurines outnumbering the female ones by four to one (Langdon 1999, p. 25). However these figurines were not only the result of social changes. Instead, they have also to be seen as active agents in this process of social transformation through their various interrelated material and contextual aspects which included their occurrence in solely sanctuary contexts, their exhibition in communal cult environments, as well as their long-lasting material form, namely bronze. It was through their material attributes and public display that these anthropomorphic figurines signified, but also reinforced and rooted the redefined notions of male and female of Early Iron Age Greece. Furthermore, the bronze figurines 'support a theoretical pattern of figurine use as an aggressive strategy in the male domination of religious developments' (Langdon 1999, p. 25) which further highlights the active role of the votive offerings embedded in the social formation of early Greece as they have been both marking and contributing to social changes and the self-definition of gender (for a discussion of this topic see below Chapter 9.2.3).

Archaeological research has focused on the material aspects of religion since this is the only evidence that survives archaeologically (e.g. see Blake 2005 for a review of material evidence of past ritual practice). Nonetheless, the importance of the cognitive aspects of cult including the beliefs, bodily actions, prayers and ideologies involved also need to be emphasized (Keane 2008). Meanwhile, the potentials of the study of the materiality of ancient religion still remain to be explored further as research traditionally has focused on, and has also partly constructed, a distinction between cult and its material expressions. Although many studies emphasise that both the aforementioned aspects are two sides of the same coin, the active role of material forms in the construction of sanctity have often been under-evaluated.

Below, the social, economic and ideological role of the bronze decorative offerings is dealt with having the Early Iron Age metal offerings as a starting point. The metal dedications are taken as more than just objects 'left at the altar'. They were rather integral elements of Early Iron Age social formation that played an active role in constructing contemporary religious thought and communal memory. Finally, they are also seen as material agents that bear multiple meanings and as such they have fulfilled different social functions including maintaining social balances through the voluntary participation of the involved social groups.

A note on the signification of metal dedications

Drawing from the structuralist school of thought in archaeology and following the concept that ceramic variation should been seen as food preparation rather than a useful collection of vessels (Hodder 1982, p. viii), the question arises as to what did the metal votive offerings of early Greece 'translate to'? Surely it was not 'copper and tin and a little bit of lead' that members of Early Iron Age Greek society had in mind each time they confronted such an artefact, but rather a series of complex meanings were communicated through the process of their ritual deposition, exhibition, and accumulation. Hence, additional questions arise regarding the possibility of different messages being communicated to the human agents when encountering these objects in religious and secular contexts, and which were these communicated ideas, as well as which were the meanings that were evoked by the different social members involved in their life cycle such as their owners, recipients, i.e. the sanctuary administration, members of different social groups/strata, foreigners, or the craftsmen.

While the process of 'reading' material culture on the basis of symbolic bilateral oppositions has been criticized as 'narrow definition of objects as carriers of information, […] and not as actively conveying meaning in a multiplicity of ways' (Jones 2007, pp. 13–15) based often on 'unproved underlying assumptions' (Trigger 2006, p. 211), the idea that objects themselves communicated the complex ideologies of their cultural environment still highlights the relationship between things and thoughts. Below an attempt to reconstruct the link between the aforementioned object-idea relationship in Early Iron Age Greece follows taking into consideration the contemporary socio-cultural context. Finally, the potential of objects not only to carry but also to create information, memories and cultural attitudes is explored.

9.2.1 What money can't buy: the social role of copper-based votive offerings

In Early Iron Age Greece and the post-Mycenaean era 'temples, rather than palaces, became the symbols of communal consciousness and economic success' (Sherratt and Sherratt 1993, p. 362). The above statement successfully highlights the crucial role of these primarily religious contexts in the economic and social organisation of early Greek society. Similarly, bronze votive offerings deposited in the sanctuaries of early Greece, as discussed also above (see Introduction and Chapter 1), have to be seen as meaningful entities with strong symbolic aspects both in terms of religious and socio-economic expressions. The act of metal offerings dedication at the Early Iron Age sanctuaries entailed multiple notions including religious humbleness, economic prowess, social recognition, and political competition. These messages were communicated by the devotees not only to the sanctuary administration, but to social formation as a whole.

Discussion of the 'value' of these votive offerings includes the strictly economic definition (as discussed above), but also their social, cultural and symbolic worth communicated through their signification during the various stages of their consumption and deposition. Following the discussion of the production stages of the copper-based dedications (see above Chapter 9.1), here aspects of their life cycles which include their consumption, sacrificial removal from circulation, discard, and hoarding are discussed. Such characteristics common across the early Greek communities have been considered rather than their circumstantial, regional particularities. Taking into consideration the various stages of these objects' life-cycles, the amount of the research that merely focuses on their religious aspects is striking as despite their integral role in the realisation of religious sentiments, they were also material commodities which fulfilled multiple social and cultural roles.

9.2.1.1 The social organisation of early Greece

The degree of diversity amongst the social organisation of Early Iron Age Greek communities has been often emphasised. Meanwhile, definitions of early, pre-state Greek society have been often produced by comparison to the Late Bronze Age palace organisation. For instance, Whitley (1991b, pp. 344–345) has argued for great social diversity of post-Mycenaean and pre-literate Greece on the basis of the diversity in the material culture including the emergence of regional pottery styles, the variety of the settlement patterns, or on the basis of ethnographic evidence – a method often seen in the discussion of this topic (Lemos 2002, p. 217). Overall, the discussion of 'Dark Age' society seems to have been largely the result of a balance between two realities, namely that of the Mycenaean palaces and a partly fictional one as it is delineated in the Homeric epics.

Despite that the various communities spread over mainland Greece and the islands were not in any way under a common, uniform political entity, their social organisation was not alien to each other. Early Iron Age society is seen in the context of this study (if indeed such a definition could be provided or justified in just a few lines) as a collection of communities each with particular attributes of local character as reflected in the emergence of distinct regional styles, but also as sharing certain underlying patterns of a common internal organisation. For example, different sanctuaries found in mainland Greece and the islands may have fulfilled the particular needs of the local communities which might not have been uniform across the Greek region, but a) the presence of sanctuaries themselves and b) some additional characteristics such as their roughly contemporaneous foundation or the fact that they did address fundamental social functions as meeting places of local communities even if these functions were not identical, all suggest some degree of uniformity. Similarly, in the record of the metal votive offerings certain regional variations occur as the nature of the artefacts dedicated to the different sanctuaries might present differences. For example, significantly many more tripods were dedicated to the sanctuaries at Delphi or Samos as opposed to that of Pherae, but again the act of the deposition of copper-based objects and vessels in these cult sites has been a rather common denominator for contemporary communities.

The hierarchical nature of these pre-state communities is largely agreed on based on the material record and the Homeric epics. Consequently, early Greek communities have been typically regarded as rather stratified where an elite or upper social stratum would have emerged partly as a result of trading endeavours with the rest of the Mediterranean as, for example, seen in Lefkandi whose material record attests contacts with the Syro-Palestinian coast, as well as from the emergence of 'big men' whose role as leaders of these pre-state communities would have cultivated a circle of political power (Donlan 1989, Lemos 2002, pp. 217–218). These prominent, ruling groups must have controlled the means to international trade and power enforcement via ideological processes (note: ideology is hereby defined following the Marxist view as a set of beliefs which are constructed by the dominant, ruling strata of society, but which members of the social formation conceive rather as unquestionable, natural laws). Considering the circulation of the metal commodities of adornment, it is hereby argued that only the ruling groups of early Greek society would have regular and casual access to these. And, thus, only these groups would have the luxury to sacrifice the metal artefacts while they could still practically be used, i.e. they were not broken or deformed. In light of the above, the dedication of valuable commodities is seen as communicating messages of power dominance which promoted the self-definition of the ruling and the politically influential groups of early Greek society.

9.2.1.2 Left at the altar: the invaluable commodities

Object biographies of votive offerings highlight their inability to return to circulation once dedicated within the sanctuary grounds. This practice is well illustrated in the archaeological record where thousands of such objects have been recovered from special deposits in sanctuaries, but also from Classical written records which explicitly describe the above practice (Linders 1987) (see also Chapter 1.2.2). Despite the later date of this literary evidence, it is still considered of some value for the preceding Geometric and Archaic periods on the basis of the massive amounts of objects recovered. Thus, it was great wealth that it was represented in the metal objects' hoarding and cultic safekeeping. Even though they could not return to circulation, they still retained their economic value and the potential of wealth which would have been enhanced by their added symbolic value which would have been attached from the moment of their sacrificial deposition.

Through the metal objects collection and safekeeping by the sanctuary administration and a significant proportion of the ruling class(es) wealth gradually accumulated in Early Iron Age Greek sanctuaries. Despite the metal objects' alleged inability to be traded anew, the potential wealth that these hoards represented was socially important in that it could still be used in periods of crisis and under extreme circumstances as seen from Classical period records. Even though there is no literary record to support the above for the Geometric and Archaic periods, it is logical to hypothesise that a certain value was still represented in the collection of several thousand votive metal objects. Even if these could not be bought or sold privately by individual members of the society, they were still under the control of the ruling groups which would have been provided with an additional opportunity to exercise political power. Overall, the deposited metal offerings despite their seemingly static status functioned almost as a 'soft pillow' for the social formation as a whole in that they would still represent the wealth, power, influence and economic potential of the ruling stratum(-a).

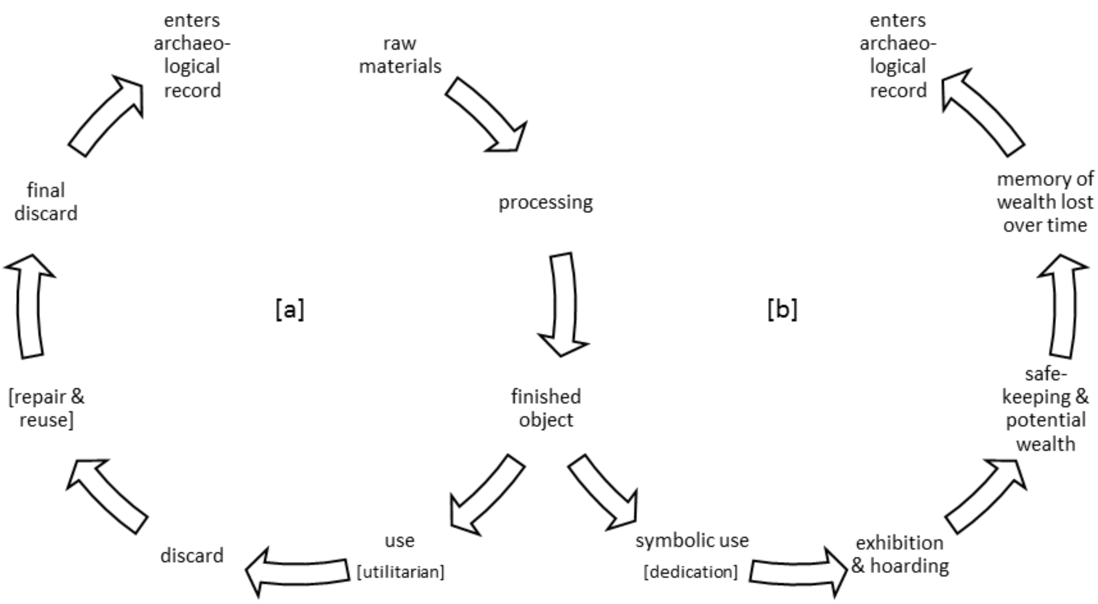


Figure 9.22. Object biography diagrams for a) objects' life-cycle in general, and b) the suggested life-cycle for the metal votive offerings in early Greek sanctuaries

Considering this potential wealth's recovery that these objects represented, it is argued that they were never finally discarded. Instead they were still valuable in their hoarding and burial in the special deposits. This potential that these objects entailed moves from a reconsideration of a traditional object life-history cycle (Figure 9.22a) towards one where the objects are not discarded in the strict sense of the term, but they are rather gradually forgotten as they ceased to be used when they were no longer part of the social, collective memory (Figure 9.22b). Instead their usefulness after deposition and burial had undergone a transformation. They could not anymore be worn or used for decoration purposes by their original owners, but their new ownership, i.e. the sanctuary administration legitimised by the gods themselves, would have been in a position to potentially utilise them.

This is different to the final discard of other artefacts which are typically discarded when there is no intention for their further use. For instance, a pottery vessel broken and deemed beyond repair would have been discarded if there was no further intention to use it as a whole or recycle it in parts such as for tempering clay. This is not the case for the metal votive offerings deposited in the Early Iron Age sanctuaries as their safe-keeping within the sanctuary grounds also meant that at any point they could be used in their present form or after remelting and recycling. Thus, in their presence alone they still held a certain dynamic which is highlighted by their preservation in the archaeological record.

To conclude, the ritual hoarding of the copper-based artefacts promoted social balance and regulated life amongst the different social strata of the respective communities through the reassurance that this potential wealth provided, but also their assumed control by the ruling groups. Even though they could not anymore be traded, they entailed a face value still recognised by the social formation. Finally, even though at this stage it is impossible to argue for a specific face value of these objects' value which might not have been able to directly translate to value measuring units, it is still important to stress the thousands of metal votive offerings under the control of the ruling social groups which were handled by the sanctuary administration.

9.2.1.3 Early Greeks 'always paid their debts': a pre-state form of tax collection?

The ritual deposition of metal offerings sustained social cohesion and balance by the semi-formal, semi-voluntary practice of the offering of a proportion of wealth by the more affluent social groups. This practice would have functioned as a form of pre-state tax collection in that a relatively standardised proportion of the wealth owned by the upper strata, which would have been the ones able to afford these metal offerings, was dedicated to the cult institutions. The above highlights further the role of communal contribution in the form of copper-based objects' votive deposition within the socio-economic context of early Greece.

Early Iron Age economy and social organisation have been much discussed amongst scholars which primarily aimed to understand the processes which led from the centralised, redistributive palace economy of the Late Bronze Age to that of the city-states from the Archaic period onwards (e.g. Sherratt and Sherratt 1993, Tandy 1997, Lyttkens 2013). However, most of these theses have largely relied on written sources (Morris 2005) a fact that presents a certain problematic regarding the pre-literate society of the Protogeometric and Geometric periods. However, the passing from the state control of the high value commodities' trading activity to that of merchant enterprise and the emergence of privately stimulated entrepreneurship has been defined as one of the main characteristics of this period's economic activity (Sherratt and Sherratt 1993, pp. 361–362). The latter would have also been reinforced by the emergence of 'market relationships' which became more pronounced from the 6th century onwards (Lyttkens 2010), but which also started to emerge with the organisation of the seasonal cult festivals held at the sanctuaries throughout Greece from the Geometric period onwards such as the renowned Olympic Games which were first held in 776 BC.

The material contribution of the wealthier individuals for the benefit of the greater society has been a familiar notion amongst ancient Greek communities. During the centuries following the Geometric period, there is substantial evidence for the Athenian society providing incentives for its affluent citizens to 'signal their wealth' and exhibit their socio-political influence by creating opportunities such as the *liturgies* and *choregies*, namely various functions which aimed at the common good and were financed by affluent citizens (Lyttkens 1997, p. 462). This was succeeded via public spending through processes which were the result of an 'interplay between formal and informal rules, between institutions and individual [endeavour]' (ibid.). Thus, the act of the ritual dedication of metal artefacts entailed multiple meanings and functions including that of an equivalent of an early, pre-state tax collection system. Only those who belonged to this group which could afford to own or, in fact, afford to purchase for the sole purpose of cult dedication, were obliged to contribute to the economic stability of the sanctuary institutions throughout Greece. Even though no literary evidence of this sort has survived for such an early period of Greek antiquity, this practice would have been semi-formal, but at the same time semi-voluntary too. Regardless of whether it was a 'legal requirement', as for example taxation during the Classical period, it would have been more than a spontaneous act of piety as it would have been rather dictated by social pressure and the expectations raised by the existing social forces. Such a socio-economic function of the copper-based artefacts would have also functioned as a duty, namely a customs tax or tariff, taking into consideration the importance of boundaries in these early Greek communities and the integral role of the sanctuaries in the process of geographical and cultural boundary negotiation.

In the Iron Age context, the accumulation of thousands of metal votive offerings need not only be seen as a romanticised act of religious humility and expression, but instead should be treated as an established and socially dictated form of communal behaviour which ensured and promoted social balance. The collapse of the Mycenaean palaces and with them the redistributive trade network forced a reorganisation not only of trade and exchange, but also of how 'status and wealth were handled' (Tandy 1997, p. 4). Furthermore, this suggested early stage of a tax system would have come hand-in-hand with the first evidence for private ownership of property in early Greece (ibid.). This form of taxation in disguise backed up by notions of divinity and fear for the supernatural could further suggest the degree to which the actual deposition of metal artefacts was in itself a practice well-embedded in Greek society already from the Early Iron Age that could also help to create a sense of belonging and reinforce bonds between social groups.

Finally, this act of religious dedication and duty paid that the devotees provided evidence for their recognition of the social, economic and political function(s) represented by the role of the sanctuaries. Through sacrifice, affluent individuals themselves were being recognised by society as individuals contributing to and accepting the rules of the social formation which by extension rendered them socially accepted agents. Thus, such willingly participating agents did not threaten the communal reality and contemporary social conventions, but instead they supported and promoted it, and shared the values of the dominant ideology.

9.2.1.4 Making connections; building ideologies

The copper-based offerings provided a common ground for identity negotiation, as well as social recognition and the self-establishment of individuals in the ruling classes within a single and/or across different communities of early Greece. More specifically, the focus is rather directed on those metal articles which would be worn and borne by the members of these communities as opposed to the artefacts which would have been used for other decorative purposes such as the pendants or the animal figurines. The potential of dress ornaments and jewellery to signify identity and communicate multiple meanings has been much explored both by archaeologists and anthropologists (e.g. Miller 2010, Moletsane *et al.* 2012, Lee 2015). And, a link between expressions of ethnicity and the material forms of dress ornaments, e.g. pins and fibulae, would be a rather simplistic approach (Lee 2015, p. 286). For instance, Curta (2005) discussed the role of the Slavic bow fibulae in 7^{th} century AD Greece and concluded that apart from being valued objects, they also contributed to the negotiation of social power and a sense of identity for local elites of the Byzantine period through their style and iconography, depending if importations or local imitations were employed each time. Moreover, the fibulae worn by the female 'mirrored the construction of the social identity of their husbands' (Curta 2005, p. 133).

Below, the structuralist influence in the interpretation of the material culture could prove useful in understanding the complex and multiple meanings communicated via the public exhibition of the copper-based artefacts. These objects, beyond their purely utilitarian functions such as to adorn the body and/or to keep in place garments, would have communicated additional messages through their various attributes including their materials, colour, style, and/or size. With the above in mind, certain questions arise such as how were these objects perceived by the individuals within sanctuary grounds, but also in secular contexts when they would still entail and communicate the potential of a unique interaction with the transcendent powers? Which messages did their bearers intend to communicate and which messages were communicated unwillingly? Did the possibility of an artefact to be dedicated transform the wearing a bronze fibula or a ring from an act of following contemporary fashion trends to one of religious humbleness? And, if so, where did the boundary between the above two aspects lay? Finally, how important was the role of social peer pressure in the processes of use and deposition of these artefacts?

Even nowadays articles of personal adornment with primarily religious connotations often become part of the dominant trends for a given period of time to the point that their cult attributes get diluted in popular culture. For example, small cross pendants or bracelets with representations of religious figures have been worn, resulting in the communication of multiple meanings. Hence, they could communicate the religious affiliation of their owner, but usually it is a larger set of meanings that are shared between the bearer and the community such as the former's agreement with certain political ideologies, as well as the ability and willingness of acquiring such an article following contemporary trends.

The nature of the bronze objects' connotations communicated upon sight can be further understood also in conjunction with the coming of the new metal in the post-Mycenaean era, namely that of iron. Iron was much more broadly available geologically and easily obtained compared to bronze whose prerequisite was the importation of tin which was scarce, close to inexistent in mainland Greece and the Aegean (see also Appendix V). Thus, there lies the possibility that bronze objects in the Early Iron Age context would have acquired an additional symbolism in that they created certain links with the ruling class of the past, namely the Mycenaean kinship(s), which would further justify the ruling of the emerging groups via processes of propaganda and memory construction by building a relationship with a glorified past (see also below this Chapter 9.2.2). Such political propaganda would have been further communicated by the ritual dedication of these artefacts which would have promoted their special role by creating links not only with the heroes of the past, but with the powerful gods and divine entities too. The bronze objects' secular circulation and utilitarian uses would have functioned as a reminder of this connection between the elite and transcendent powers. The above connections would have been manifested even without the actual dedication of the objects as their mere possibility of dedication alone would have been a strong reminder of the political standing of the elite groups and would have reinforced the underlying ideologies. Amongst the social functions of the copper-based artefacts was the creation of bonds between individual members of the upper social groups/strata, as well as marked certain ideologies. The latter can be seen as a process of drawing and/or maintaining social boundaries, as well as deeply rooting the power of these elite groups; processes which would all prevent these groups' status from being challenged. Bearing such valuable commodities in the reality of Early Iron Age Greece was in a sense a form of *branding* for the ruling groups whose power was still emerging, in that it contributed to their self-definition. For instance, the members of the community which could afford to wear a pair of bronze fibulae to support their garment were by such actions also making strong statements regarding their social standing within their own community, but also they communicated their status to members of other communities too, both Greek and foreign.

Overall, the act of metal object votive deposition was multi-dimensional and it reassured society of one's willingness to communicate with the gods and to be parted of their valued bronze objects despite whether they were long owned or purposefully acquired for the sake of the offering itself. It promoted the self-establishment of the emerging ruling social groups and, thus, the social stability needed for economic growth. With the development of a new economic model based more on individual endeavour rather than on state control, new forms of social control were needed and the metal objects' dedication played its role. Finally, religious institutions accumulating wealth and private ownership leading to massive debt that only redistribution of wealth could solve such as by Solon's legislation in 6th century BC Athens is not a scenario only of the distant past.

9.2.2 Communal memory and materiality

> 'Both objects and people are engaged in the process of remembering, in that objects provide humans with the ground for experience'
>
> (Jones 2007, p. 22).

The concept of memory and its relation to past societies has attracted some attention amongst the community of archaeologists during the last few decades (see Rowlands 1993 for an example of early work on memory in archaeology). However, it has been mostly from the 2000s onwards that this field's potentials have been explored in more depth (e.g. Hendon 2000, Alcock 2002, Williams 2003, Jones 2007, Barbiera *et al.* 2009, Meirion Jones and Bradley 2012, Hamilakis 2013, Cosmopoulos 2014). Meanwhile, such pursuits have traditionally been more attractive to professionals with varied backgrounds such as sociologists, anthropologists, psychologists and neuroscientists whose research foci led to interdisciplinary approaches on the concept of memory and its role in ancient communities. For instance, the work of Donald (1991, 1993) who focused on an evolutionary model for human cognition has been influential on archaeological thought of the last couple of decades despite the criticism that it has attracted (see e.g. Renfrew and Scarre 1998, and Jones 2007 for a constructive critique on Donald's three stage model of human culture and cognition).

Following the discussion of the social, religious and economic contributions of the metal votive offerings (see above this Chapter 9.2.1), their interrelations with and within the Early Iron Age Greek society through their materiality and the processes of their handling, manipulation and interpretation by the human agents are further explored. Even though studies of memory in archaeology have often focused on grave offerings as a means to reconstruct past processes of ancestor remembrance (e.g. Chesson 2001, Kuijt 2001, Williams 2003, Barbiera 2009a), here concepts emphasis is put on (a) how material culture may assist societies in remembering and the impact of collective modes of remembrance on individuals' perceptions, (b) how it affects and shapes social actions, as well as (c) the relationship between social memory and identity. Rather than having a focus on a 'mere exploration of how societies remember' (Jones 2007, p. 5), material culture is seen not only as a vessel, as argued by Donald, but also as an active agent (ibid.) which contributed in processes of shared social memory construction and, in turn, promoted a sense of common identity for the peoples of early Greece that would shape society for succeeding periods. Through such processes, social memory is not only a means of approaching things that have gone, but more importantly it is in a position to shape things that have not yet come to pass. Consequently, the metal dedications at the Early Iron Age sanctuaries of Greece, amongst other social functions that they were fulfilling (see above), were also contributing to the construction and preservation of collective social memory through processes of their exhibition and hoarding as they have been part of a wider ideological framework which turned towards strategies of remembrance and self-identification in order to legitimise power and social prevalence of the emerging ruling groups.

9.2.2.1 Narrative, permanence, and memory construction in Early Iron Age Greece

Before the metal dedications are more closely explored, additional elements of the broader social context of early Greek communities and the transformations that were in process during the Early Iron Age which, as argued, contributed the social memory construction are reviewed. During the 8^{th} and 7^{th} centuries BC in Greece and the Aegean developments which largely sprung from the post-Mycenaean and Protogeometric periods that influenced and defined Greece later in the Classical and Hellenistic periods took place. These have been manifested in various aspects of everyday and communal life of Greek society including the introduction of a new writing system, the re-emergence of representational art, the development of urbanisation and expressions of monumentality.

Forms of both representational visual art and written communication that have been a part of Late Bronze Age society have been disrupted in the following period only to re-emerge during the Geometric in the mid-8^{th} century BC. Their re-introduction in the late Geometric and Archaic periods and even their co-occurrence in Archaic pottery where figures and inscriptions were both featured established themselves as integral aspects of Greek society by linking the mythological distant past with the reality and the circumstances of the presence (Osborne 1998, pp. 19–20). Furthermore, they did not directly relate to the Late Bronze Age circumstances as both these elements acquired additional meanings and new functions in the 1^{st} millennium BC. For example, the writing system of the Iron Age which was based on an adaptation of the imported Phoenician alphabet had little in common with the Mycenaean writing practice as it moved beyond the primarily administrative recording methods of the palaces. Writing in the post-Mycenaean era developed to become a useful tool which promoted communication based on narrative forms as, for example, seen in the attempts of poetry and historiography by Hesiod (late 8^{th}-early 7^{th} century BC) and Herodotus (5^{th} century BC) respectively. Additionally, the passing from a purely geometric concept to representations of real life events in art from mid-8^{th} century BC onwards (Lemos 2000, p. 11) is another form of memory construction through the commemoration of significant events linked to various aspects of life and death of Early Iron Age Greece, such as depicted in the Geometric amphorae and craters from Kerameikos cemetery in Athens.

The relationship between writing and the concept of memory has been identified already by ancient authors such as Plato who while discussing rhetoric and writing described the latter as primarily 'a memory aid' in one of his dialogues presumably written around 370 BC (*Pheadrus*, 275d) (Coulmas 2003, p. 5). He, thus, diminished the writing's vital role in interpersonal communication in favour of this for memory construction. In addition, the contribution of writing and representational art in the city-state organisation of early Greece has been suggested by Donald (1991, 1993, p. 749) to mark the third stage of his evolutionary model for the development of human cognition, namely that of 'theoretic culture', via the utilisation of 'external symbolic storage' typified by literacy, urbanisation, and the rise of the Greek city-states (in: Jones 2007, p. 6). Despite Donald's critique by Renfrew (1998b) who argued that little attention was paid to the material culture of early human societies, or the associated problems identified by Jones (2007, pp. 6–12) such as the treatment of the mind as an isolated and disembodied entity, the emphasis on the contribution and impact of writing and representation systems on the shaping of social cognition and their important role in the processes of creation and preservation of communal memory is worth retaining. Furthermore, the relationship of writing systems and urbanisation has been stressed by Le Goff (1992, p. 55) as well who has appointed the passing from orality to writing to mark a transition from 'ethnic', less developed memory to more highly organised memory practices which enabled new mnemonic strategies associated with emerging urban contexts (Olick and Robbins 1998, p. 114). Finally, despite that a new writing system was introduced only from the late 8th century onwards, the importance of objects and symbols in the excitation of communal memory and imagination may have become even more pronounced and crucial at times when written communication was not employed (Barbiera 2009b, p. 18).

Nonetheless, urbanisation need not necessarily be seen as the inevitable result of a long evolutionary developmental process, but rather as circumstantial and as dependent on the juxtaposition between town and its immediate periphery that takes into consideration the particularities of each site (Damgaard Andersen *et al.* 1997, p. 11). The above definition could prove useful in understanding the various Early Iron Age Greek communities which do not necessarily fit into the less flexible division of city-state/ethnos or urban entity/big place as defined by Morgan (2003). A similar definition of urbanisation can, for instance, be used in order to account for the differences amongst the social organisation of the various Early Iron Age Greek ethne including the Thessalian one which not all shared a set of common characteristics (op. cit.). Furthermore, it was the view of urbanisation as a 'large-scale effort to structuring the material environment' along with processes of social complexity that led Donald to argue for its contribution to memory construction via the 'externalisation of memory and amplification of permanence' by ideological projections on the respective material records (Donald 1998, p. 181).

Drawing from the above, expressions of monumentality that took place during the Geometric and Archaic periods were contributing to the construction and shaping of a sense of communality and social memory. This was achieved not only by means of large constructions, but also of durable material forms which would have promoted notions of catholicity and permanence through their resistance in the decay of time and their potential to be passed down to succeeding generations. In addition, monuments along with narrative (see above) contributed to memory construction by rendering the materiality of memory 'user-friendly' (Steiner and Zelizer 1995, p. 232). Such expressions can be seen in the creation of a structured environment (see urbanisation above), but also in the construction of large scale temple architecture and a general turn to time-resistant material forms such as stone (poros) and marble. The Early Iron Age stone temples which have started to be erected form the 8th century onwards and often replaced structures of perishable material such as wood and mudbricks, as also suggested for the case of the Pheraean temple too, must have left an imprint not only on the landscape, but also on the peoples' minds contributing, thus, to the creation of perceptions on the idea of divinity. In Early Iron Age Greece, gods' homes were visible from afar, grandiose, and at the same time foci of identity self-definition and negotiation statements of authority. Certain architectural features recurring in the Greek temples must have also contributed to the formalisation of common perceptions and ideologies amongst contemporary communities' members.

An additional example of expression of monumentality can also be seen in the first stone *kouroi* (=nude male free-standing sculptures) which first appeared from mid-7th century BC onwards as suggested by examples recovered from the island of Delos in the Cyclades (Richter 1988). Such sculptures, almost like the temples themselves, would have created an impression not only due to their oversized dimensions, but also through the durability of their material which would allow their long lasting public admiration.

9.2.2.2 Small monuments: metal votive offerings and social memory

Metal artefacts in Geometric and Archaic Greece can be seen as 'small monuments' themselves. Their monumentality in not to be found in their size, even though some oversized bronze objects have been discussed above (e.g. see the two massive Thessalian leaded fibulae discussed in Chapter 7.3.1.2), but rather on their material properties, the various meanings they borne and communicated, as well as on the sanctity and importance of their religious deposition itself. For copper-based votive offerings it was not only their durability and resistance to the consumption of time that potentially rendered a sense of monumentality, but also their ability to bring human agents in communication with transcendent powerful entities and to please and appease the latter through the act of dedication.

Religious sacrifice was an act strongly associated with the notion of permanence to which the bronze offerings' material durability and their inability to return to circulation once deposited added further. Copper-based votive offerings themselves and their religious deposition entailed a sense of permanence and continuity, a material and symbolic one, which ensured their preservation in the future which was allowed both by their material properties, as well as the important messages they carried with them; the messages to the gods, but also the ones communicated to the society. Their dedication in the sanctuaries reassured the social formation of the individuals' willingness to abide with the social conventions and participate in communal activities; a reassurance that these dedicators were not a threat to the contemporary social formation, but instead were contributing members of the community and acquiescent of the collective ideology and the principles attached to the latter.

Consequently the massive deposition of thousands of metal offerings contributed to the circumstances which led to the urban character of the Greek communities from the Archaic period onwards as seen in the social, political and legal organisation of these communities, as well as in their colonial enterprises and foreign contacts. The mere processes of storing and hoarding such as the accumulation of thousands of bronzes in the Early Iron Age sanctuaries were integrated into the construction of memory 'through which prestige was created and power validated', while the 'visibility of these [processes] opened them up to social comment, creating histories vital to the production of social memory'(Hendon 2000, p. 49). Finally, special objects and symbols displayed during public rituals and ceremonies, or visible in everyday social interactions would have been actively employed to the legitimisation of power positions and the promotion of ideas of continuity at a time when significant social changes took place (Barbiera 2009b). In the context laid out above, the exhibition of the bronze offerings in the sanctuaries was an act of establishing and legitimising social prevalence and political power, while memory construction has been linked to the ruling or upper classes and as, Chapman noted, 'it is not only history written by the victors but memory-work too' (2009, p. 12).

9.2.2.3 Constructing a shared future

The past as perceived by the individuals can be defined as a mere 'collection of memories', while memories themselves should be seen as 'created, rather than as simply and passively received' (Schacter 1995, pp. x, 428). Social, cultural or collective memory can be, in turn, defined as a set of 'recollections that are instantiated beyond the individual by and for the collective' (Steiner and Zelizer 1995, p. 214) or as 'an expression of collective experience as it identifies a group, giving it a sense of its past and defining aspirations for the future' (Fentress and Wickham 1992, in: Cosmopoulos 2014, p. 423). In addition, elements of the surrounding environment are responsible for stipulating specific memories (Alcock 2002, p. 4) and, thus, the material world itself contributes to the creation of a shared past for the respective communities. By extension, material culture also contributes to the formation of a shared future through processes of negotiation of collective identities such as by promoting communication and by providing a ground for the various forms of personal and collective expression to take place and be developed and transformed through time. Thus, if 'material culture is able to externalise memory' (Donald 1998), the former is not only able to 'store', but also to create memory. Being surrounded by time-resistant material forms, and actions and rituals which entail a sense of permanence as discussed above, memory and social memory, in particular, are shaped, reinforced and passed down to succeeding generations. By constructing memories, one is also constructing a shared past (e.g. Bond and Gilliam 1994, Pennebaker *et al.* 1997, and Damaskos and Plantzos 2008 for various views on the use of the past in the construction of modern Greek identity), while collective memory has the potential of constructing a future too through its effect on future circumstances via processes which reinforce the sense of a collective identity and shared ideologies.

The contribution of material forms and material culture in collective memory construction is immense. Collective memory 'presumes activities of sharing, discussion, negotiations and, often, contestation' (Steiner and Zelizer 1995, p. 214), and at the same time it is material, it has texture, it exists in the world rather than in a person's head, and so is embodied in different cultural forms as it is also found in objects (ibid., p. 232). Each interaction between people and artefacts produces memory (Jones 2007, p. 2).

The role of memory creation at times of social change has been often emphasised such as in the recurring bronze statuette of the Peacock Angel which has been typically used in order to reinforce traditional religious authority via creating links with the tradition amongst Yezidis, a Kurdish religious minority, which until very recently did not make use of any written records (Spät 2009, p. 105). Similarly, through the bronze votive offerings and their acts of deposition at the Early Iron Age sanctuaries the private and shared communal experiences were commemorated, while the metal offerings themselves were the material manifestations of an ideological context which promoted social cohesion in the post-Mycenaean era. In the absence of the form of centralised authority as exercised by the Late Bronze Age palaces, Early Iron Age Greek communities were engaged in a process of self-definition and future image construction through these acts of metal object religious deposition, as often seen for social groups (Barbiera 2009b, p. 18). Moreover and as also suggested by Spät (2009, p. 115), often it is not the actual items used, but rather the ideas of what they represent and the connotations that bring to mind, that are important, while the role of rituals and the appropriate objects involved in these has been emphasised as playing an important role in the emergence of a new social order (Barbiera 2009b, p. 18).

Overall, the practice of the bronzes religious deposition went hand in hand with a generalised shift towards time-proof things and which were potentially able to outlive their users such as stone temples and oversized sculptures. The contribution of the metal objects dedication reinforced the linkage of the prominent social strata with roots of the past, even if it was a relatively newly created past, with the possible aim of ensuring their dominant role in the future via the formation of a visible tradition. To conclude, the contribution of the metal objects' votive deposition to the shaping of the society lied on their physical properties and their time-resistant material form, as it did on the permanence involved in the ritual of their dedication itself. It was a means of expressing and legitimising the political and social power of the ruling strata of contemporary society by making use of religious ideology in a period of transformation for Greek society.

Chapter 10. Conclusions

The post-Mycenaean period and Early Iron Age in Greece have been the subject of considerable research and have generated a long-standing debate amongst archaeologists from the 1970s onwards. This academic interest was partly sparked due to the fact that the early 1st millennium BC bridged two rather distinguished periods of Greek antiquity, namely the Mycenaean civilisation with its cosmopolitanism and extravagant wealth and the Classical Greek culture which flourished from the 6th and 5th centuries BC. The interest for the formative years of Classical Greece has been also partly attributed a tradition inherited from the European Renaissance movement in the Late Middle Ages which re-introduced an appreciation for the Classical Greek and Roman aesthetics and ethics. Hence, the formative period of this influential period of Greek antiquity, has attracted much of archaeologists' attention since early Greek society was a non-literate one, and classicists and philologists would have little to contribute.

Over the years, different hypotheses have been formulated in order to account for the series of events that led to the collapse of the Mycenaean palaces and the events that followed, and in order to establish the degree of continuity and change before and after the Late Helladic IIIC period (ending in approximately 1050 BC) which marked the final decline of the Mycenaean culture. Even though several arguments have been put forward in the course of the last few decades, it is currently largely accepted that the Early Iron Age in Greece shared certain cultural expressions with its preceding Late Bronze Age, while new cultural forms have been also gradually introduced (for a more detailed discussion on this topic see Chapter 1).

The main aim of this thesis has been a contribution to the study of the Greek Early Iron Age by exploring aspects of its technology and copper-based metallurgy, in particular, in relation to contemporary society. By the early 1st millennium BC, copper-based production was a well-embedded element of contemporary communities as copper and bronze artefacts have been long produced in large quantities and widely used, as suggested by the available archaeological record. Even though not all members of contemporary society would have been able to afford to produce and purchase bronze artefacts at the break of the 1st millennium or the 8th century BC, it is hereby argued that it was gradually a larger proportion of the society in comparison to the rather closed royal family circles of the Mycenaean period which would have had access to such commodities. This is also illustrated in the vast quantities of bronze objects recovered from Early Iron Age contexts from mainland Greece and the islands.

The investigation of Early Iron Age Greek production of copper-based artefacts shed light to activities integral to contemporary communities that further revealed the characteristics and the mode of copper technology, and, in turn, of aspects of contemporary social organisation altogether. The present study focussed on copper-based objects in order to explore further this period of cultural transformation and to reveal elements of the organisation of its metallurgy, the degree of specialisation, standardisation, and efficiency of the technological practice, as well as to trace possible cultural interactions and the characteristics of the metallurgical workshops around Greece and the Aegean. Such an approach was considered necessary as research on the metallurgical technology and its products during the early 1st millennium Greece has been of a rather descriptive character so far, while few studies have been developed around an explanatory/interpretative framework (see e.g. Rolley *et al.* 1983). For example, detailed typological sequences have been compiled by focusing on the different artefact types' decorative characteristics which though were not in a position to reveal the complex meanings communicated by the metal artefacts or the technological and cultural choices made during their production. Even though typological studies have been quite fruitful in other contexts such as prehistoric stone tools (e.g. Aubry *et al.* 2008, Section C65), the typology's contribution in the context of Early Iron Age metal production cannot approach the subject holistically. Meanwhile, the copper-based artefacts' quantitative investigations have so far often been published as excavation reports' appendices with a focus on presenting rather than discussing in detail the generated data (e.g. Jones 1980, Riederer 2007) (for a discussion of the above see Introduction and Chapter 2).

The investigation of the assemblage of copper-based artefacts from the site of ancient Pherae in the south-eastern part of Thessaly discussed the characteristics of Early Iron Age metallurgical practice and the contemporary socio-economic circumstances. Questions put forward included the investigation of the nature of the raw materials employed, the organisation and mode of production, elements of specialisation and standardisation of contemporary copper-based technology, as well as its integration to the exploration of the broader social role of the copper-based artefacts in the consolidation and expression of the social groups involved in their production and consumption.

10.1 Copper-based technology in Early Iron Age Thessaly and Greece

Detailed examination of the assemblage from Pherae promoted the exploration of the relationship of copper technology with this particular community which could be used as a case study for early 1st millennium Greek society, while incorporation and synthesis of related published assemblages allowed the consideration of this technology in the broader context of the Greek mainland.

10.1.1 Regionality vs. universality of copper-based production

The examination of the copper-based production in Early Iron Age Greece suggested that copper technology was defined by regionality. This characteristic of early Greek metallurgical practice has been already indicated by the variety of copper and bronze artefact typologies found around the eastern Mediterranean and Asia Minor which have been attributed to different regional workshops (see above comment on typological studies). Quantitative analyses from Pherae and consideration of the available data from contemporary Greek sites reflected additional particularities of the copper technology which point to a variety of technological practices taking place including the use of different copper minerals and/or choices during ore processing, metal alloying and the shaping of the artefacts. Careful remarks regarding the raw materials used for the production of the copper-based artefacts should be made due to the nature of the available data (for a discussion of the limitations of artefacts' analyses and the comparison of different analytical techniques see Chapter 3). Consequently, cautious analyses of the study's findings suggested that a variety of technological practices has been employed by the Early Iron Age communities of Greece. Meanwhile, comparison of the available datasets suggested that characteristic metallurgical cycles (Figure 9.1) and most likely local copper sources were employed, even though it has not been possible to pin-point the use of particular ores or of specific techniques.

The employment of particular technological choices, namely minerals and/or techniques, has been, for example, reflected in the different ratios between the various trace and minor elements found in the copper (note: ratios and not absolute values of the elements have been considered in order to account for the variety of analytical instruments employed in the analyses of the different assemblages). The ratios between arsenic, iron and lead concentrations in occasions suggest the exploitation and use of specific copper ores. More specifically, two distinct patterns have been noted between the iron and arsenic concentrations. The central mainland Greek workshops, namely these of Kalapodi and the tripods from Delphi, showed on average higher respective concentrations of arsenic than of iron, whereas a different picture was noted for the assemblages from Thessaly (Pherae), Euboea (Lefkandi) and Messenia in southern Peloponnese (Nichoria) in which the iron content was higher than the arsenic one (Figure 8.20). Craddock's analyses also showed higher iron content compared to the arsenic one, but since the artefacts analysed were of mixed origin, this ratio is not informative when it comes to tracing local choices in the metallurgical practice. Amongst the higher arsenic datasets, the Pherae assemblage showed closer values to the Lefkandi ones with a median Fe/As ratio of 0.5, even though Pherae's mean ratio was larger than the Lefkandi one (Table 10.1). The geographical proximity between Pherae and Lefkandi could further justify their cultural interactions and the emergence of a similar pattern for their metallurgical practices (Figure 8.1). Similarly, particular high iron or lead concentrations such as seen in a group of Delphi tripods (Figure 8.8) and in the Epirotic fibulae (Table 7.3) respectively more likely suggest the use of specific copper sources, rather than the deliberate addition of 2-3% iron or lead. This is further seen in the rather well-defined nickel concentrations for the Delphi tripods which would have resulted as an ore impurity (Figure 8.8a).

Table 10.1. Summary table showing the iron to arsenic ratio of the mean and median values for the different datasets considered; Craddock's analyses has been excluded due to the mixed origin of the analysed artefacts

sample	Pherae	Kalapodi	Nichoria	Lefkandi	Tripods
author	Orfanou	Riederer	Rapp et al.	Orfanou	Rolley et al., 1983
year	2014	2007	1978	2009	Marangou et al., 1986
analyses	EPMA	NAA	OES	EPMA, SEM	AAS
N	70	154	23	14	115
Fe/As mean	1.0	3.8	0.9	0.7	3.4
Fe/As median	0.5	2.0	0.2	0.5	2.1

Despite the aforementioned discrepancies in the metal impurities, the metals used and the alloys produced pointed to a shared technological tradition for the various Greek communities. The different metalworking workshops not only used copper, tin and lead which must be considered as readily available in Early Iron Age Greece, but also smiths in the various workshops tended to use them in comparable proportions. Thus, even though various chemical compositions can be seen in the different copper alloy objects such as low- or medium-tin bronze, the aforementioned metals have been typically mixed in proportions to produce binary bronze with a recipe of nine parts of copper and one part of tin, that is approximately 7% to 11% tin bronze. Meanwhile, unalloyed copper or low tin bronze and leaded bronze have been more rarely used. In fact, binary bronze has been the most preferable alloy covering 65% of the objects analysed in all datasets discussed, whereas only 19% and 16% of the total objects analysed were of unalloyed copper or leaded bronze respectively (Table 10.2).

Table 10.2. Summary table of the tin content in all assemblages discussed in the study according to the alloy/metal type (Jones 1980 and Davies 1934 excluded due to low accuracy of the results)

alloy	description	Sn (wt%)			
		N	N (%)	Mean	Median
unalloyed copper	<4% Sn, <4% Pb	147	19	1.1	0.6
bronze	>4% Sn, <4% Pb	492	65	9.2	8.9
leaded bronze	>4% Sn, >4% Pb	120	16	7.4	7.3
Total		759	100	7.3	7.5

Moreover, the tin additions found in copper which are typically above 4% tin and with an average of 9% tin for the binary bronze and 7% tin for the leaded bronze (Table 10.2) point to the production of freshly alloyed copper and that enough tin was available to produce a medium tin bronze in abundance. This along with the fact that objects with contents below 4% tin have a mean tin concentration of just 1.1% tin (1.7% tin for the Pheraean assemblage, see Table 4.7) suggest the active alloying of copper with fresh tin as opposed to the use of solely recycled bronze even though it is expected that remelting and reuse of bronze artefacts would have been performed. This is, for example, suggested by the particularly small numbers of bronze artefacts from non-sanctuary or non-burial contexts of early Greece. Nonetheless, such recycling operations would have likely been accompanied by the use of additional amounts of tin until the desired medium tin-bronze recipes were achieved. Lastly, the availability of fresh tin at least from the 9th century onwards in Greece is attested by the vast numbers of copper and bronze artefacts in the archaeological record. Only the steady and continuous flow of copper and tin would have facilitated and made possible the production of such large numbers of copper-based objects as recovered from the Early Iron Age Greek sanctuaries.

Overall, the particularities in the trace and minor elements reflected the variability both in the copper sources used and possibly in the metalworking techniques employed during the manufacturing of copper and bronze artefacts during the Greek Early Iron Age, while certain elements of standardisation of the technological practice such as a general preference for a 7-9% tin bronze, reflected the influence of a well-embedded metallurgical tradition amongst Greek communities. In addition, the regional character of copper production suggests that a number of post-Mycenaean communities were in a position to exploit their locally available copper sources, as well as to acquire non-locally available tin metal or cassiterite.

10.1.2 Standardisation and specialisation: matter, form and technique

Particular decision making processes were traced in conjunction with artefact typology as the various assemblages showed evidence of particular preferences in their alloying traditions of copper. Object type, size, decoration and/or function have been found as decisive factors regarding the addition of tin and lead into copper during the Greek Early Iron Age even within a single assemblage, while the various regional workshops' copper-based artefact production was characterised by local recipes and preferences. Both the above aspects of the datasets explored here have been taken as strong indications of the level of specialisation and standardisation of contemporary copper-based production.

This specialisation of the technological practice has been well-illustrated in the ring and fibulae groups from the Pheraean assemblage. These two artefact types with some 100 and 50 fibulae and rings included in the sample have provided sufficient ground for a discussion of alloy recipes. Hence, the various rings' types and subtypes were related to particularities in the alloy recipes such as between the ring Types IVa and IVb which typically showed a preference for a 10-11% and 6% tin bronze respectively (see Chapter 7.3.2 & Figure 7.35d). Additionally, a similar pattern was found amongst the various fibulae typologies. The Thessalian, Epirotic and Helladic fibulae groups produced rather distinct alloy patterns mostly seen in their tin additions (Figure 7.23). An additional example would be the over-sized Thessalian fibulae made with the lost-wax technique which showed particularly lead-rich compositions with contents up to 20% lead, illustrating thus vividly the relationship between the artefacts' functional, aesthetic and technological attributes.

Particular alloy recipes were also preferred amongst the different copper-based assemblages, while characteristic tendencies in the tin and lead additions have been also distinguished amongst the different alloys, namely binary or ternary bronze. This has, for example, been seen in the datasets from Pherae, Kalapodi, and the Delphi tripods which each showed distinct normal distribution patterns for the addition of tin both in binary and ternary, leaded bronze. Meanwhile, often different modes for the tin additions have been seen in the binary and the leaded bronze such as in the case of Kalapodi where significantly lower tin content has been added to leaded bronze, namely a mean of 5% tin, than in the binary bronze where a mean tin content of 7-8% Sn was added (Figure 8.24). Finally, the addition of tin in the copper has been typically more standardised and better controlled than that of lead, a pattern which is also shared by the early Greek copper-based artefact assemblages (Figure 8.21 & 8.22).This degree of specialisation is an additional indication of shared practices, as well as for the regional character of copper-based metallurgical activities in Early Iron Age Greece. The distinct alloy recipes seen in the various artefact typologies and regional workshops further suggest that a long-standing metallurgical practice was established. Also, the rather mature state of the metal production and an overall good understanding of the material properties of copper and its alloys on the part of the metalsmiths is reflected. Nonetheless, the shared cultural elements and practices amongst the early Greek communities such as the ritual deposition of copper-based artefacts and the metallurgical tradition and the prevalence of tin bronze over other metals or alloys, still allowed space for distinct patterns of decision making to take place by the respective workshops as, for instance, this illustrated in the Pherae and Kalapodi datasets amongst which the former used bronze alloy richer in tin, but also in the fibulae typologies.

To sum up, a widespread metallurgical practice for early Greek society enabled the production of copper-based and bronze artefacts in distinctively large numbers. The production of copper and its alloys showed several characteristics which point to its local character and to small scale operations which would account for the aforementioned alloy recipe and artefact type correlations. Finally, despite that copper-based artefacts have been produced by the thousands during the Early Iron Age, when it came to the circumstances of their actual production these point to quite particular and specific choices having been made which were closely dependent on local technological traditions and the decision making of the metalworkers of the various regional workshops.

10.2 Copper and bronze in early Greek society

Results so far have highlighted the integral role of copper metallurgy in numerous Early Iron Age communities. Copper and its alloys have been widely used and produced by early Greek society even though it is reasonable to argue that not all communities would have had access to the means or the knowledge needed for the manufacturing of copper-based artefacts. As seen in the foundation and further development of the Early Iron Age sanctuaries where it is not clear why they emerged in certain areas and not in others, copper technology could be also seen in a similar context, an observation which further reinforces the relationship between the sanctuaries and metallurgy (see also Chapter 1.2.1). Communities which hosted emerging social groups in the aftermath of the Mycenaean period would have further promoted their technological output also as part of the broader socio-political context and their need for reinventing and establishing their status.

10.2.1 Markers and makers of identity

Copper and bronze artefacts due to their durability, their votive use and their long-term display in the Greek sanctuaries would have been a quite favourable medium for the expression of collective identity including sentiments of religious humbleness and, in turn, of political and social statements. Meanwhile, their role in the consolidation of the local upper classes was decisive since only certain groups with social standing and influence would have potentially had access to such commodities. In this context, copper and bronze artefacts have become the vehicles to carry and express the roles and identity(-ies) taken on by these emerging social groups or the upper strata of Early Iron Age Greek communities. Copper-based technology would have been well-embedded in Early Iron Age Greek society, a medium for maintaining social balances, but also for creating and enhancing the sense of belonging between the involved social groups; also as a form of self-identification by comparison to the 'other'. Hence, bronze artefacts would have been markers, but also makers of collective identity and social standing.

10.2.2 Bought or brought? Sanctuary economics and metallurgical organisation

Chemical compositions and metalworking characteristics of the copper-based dedications at the Enodia sanctuary suggest the functionality of these commodities. They consisted of hard, durable, well-worked alloys and could have been potentially used as sanctuary offerings and for everyday use. Binary bronze seems to have been particularly valued aesthetically and economically too as more than two in three copper-based objects are of tin bronze. Their design and typology including elements such as their colour, material and function should be considered as integral aspects of the objects that potentially added further to their face value despite that notions of value in antiquity and particularly during non-literate periods should not be taken as straightforward. Thus, these copper-based offerings should not be considered as cheap artefacts produced and purchased with the sole purpose of ritual deposition. Meanwhile, the two different uses, namely the cultic/symbolic and secular/utilitarian one, should not be seen as exclusive or antagonistic. For example, a ring or a fibula could have been used for a period as an article of personal adornment, while at a given stage of its life cycle could have been offered at the sanctuary. Finally, the various pendants would have retained their primarily decorative character in either an everyday or cult context.

The local Thessalian character of the vast majority of the copper-based offerings at the Enodia sanctuary as seen in both their typological and technological characteristics suggests their production in the proximity of and likely within Pherae itself. The local production of the vast majority of the metal offerings to Enodia further points to the operation of social structures at ancient Pherae during the first half of the 1st millennium BC that sustained the community's demand in copper-based commodities, as well as they promoted the economic self-sufficiency of its attached sanctuary by the accumulation and safekeeping of a substantial proportion of local wealth. Meanwhile, artefact types with typological links to non-Thessalian communities need be considered either as potentially imported or as local imitations. The group of Epirotic fibulae is the only artefact type with strong indications for non-local production origin, while it is more difficult to argue the same for additional artefact types at the present state of research due to sample size. The above highlights the strong presence and involvement of the local Pheraean community in the religious activities and the consolidation of its emerging political and economic power which was markedly seen in the second half of the 1st millennium BC.

10.3 Future research

Building on from the current state of research and this study's results, additional work on the copper-based production holds the potential of revealing in greater detail the characteristics of the metallurgical technology and promoting further the discussion of the social organisation of Early Iron Age as Greek communities. A number of individuals and social groups have contributed in the copper-based production as it required an established network of communications for the extraction, transportation and/or importation of raw materials, and the manufacturing of commodities. The present study addressed the above topics by focusing on the objects' life cycle, the standardisation of production, and the metallurgical technology over a wide geographical region with the aid of published data. Additional work such as comparative analyses of additional assemblages such as these of Olympia, Samos or the one from the sanctuary of Athena Itonia at Philia in Thessaly would enhance our current understanding of the early Greek society and the circumstances which lead to the Archaic and Classical periods and which saw the re-introduction of literacy, and the inception of historiography, democracy and coinage. Examination of the Itonia sanctuary due to its geo-political associations with Pherae, would promote further the understanding of contemporary Thessalian communities and their strong ethnic ties, as well as the role of Pherae amongst them and its social and political organisation which led to its prevalence along with Larissa and ultimately to the formation of the Thessalian *koinon* in the Hellenistic period (Graninger 2011).

Furthermore, a synthetic study of the copper-based objects and the recording and analysis of the available by-products of the metallurgical operations, such as slag, furnace or crucible fragments, from various sites all over Greece and the Aegean, would promote the understanding of the character of contemporary copper technology, as well as the nature and characteristics of the communities to which such as activities were practiced. Supplementary analyses conducted with lower detection limit instruments, such as ICP-MS, would also enable the examination of the trace element concentrations with greater accuracy and, thus, revealing more on the objects' technology. Such a focus in conjunction with surveying and analysing copper outcrops of mainland Greece such as these on Mount Othrys and the Pagaeon Mountain which have provided evidence of exploitation during antiquity (see also Figure 2.1) could help to draw a clearer picture for the exploitation of copper sources and their circulation amongst and utilisation by post-Mycenaean communities.

Examination of specific artefact types such as the fibulae or the Macedonian bronzes from a wide geographical and chronological angle could provide information on the diachronic changes and patterns of technological knowledge transmission between different cultural groups since similar artefact types have been used and possibly manufactured by a number of different communities over the course of several centuries. Finally, a cross-technological approach looking at the relationship between copper and other non-ferrous metallurgical operations with that of the iron or precious metals production would provide a holistic approach on the nature of Early Iron Age metallurgy in Greece.

Final remarks

To conclude, Early Iron Age copper-based technology was a rather closely controlled, well-rooted and well-organised practice. Even though certain regional variations and preferences did occur amongst the regional metal workshops, other characteristics point to the prevalence of a common background of technological knowledge, access to raw materials and decision making patterns. Moreover, considerable degree of standardisation took place as seen in the particular chemical compositions or even the copper ores used for the production of specific artefact types such as, for example, the lead-rich Epirotic fibulae or the iron-rich Delphi tripods. In addition, substantial understanding of the properties of metals and alloys used took place leading to maximising the efficiency of the technological practice as, for example, seen in the degree of the labour invested. Meanwhile, a marked preference for binary tin bronze seen raises further issues of aesthetics, as well as the social value of these objects and their role in facilitating the promotion and establishment of the emerging groups' identity(-ies). Bronze objects played an active role in the maintaining of social balances and identity negotiation of local ruling groups, and altogether to the circumstances which facilitated urbanisation in the 1st millennium BC and the formation of the city-states in the Archaic period. Overall, copper and bronze production in early Greece was widely practiced and was embedded in local communities, whilst it also served as a vehicle for non-verbal communication and identity negotiation of the emerging communities.

Reference list

Adrimi-Sismani, V., 1983. Τύμβος Φερών. *AAA*, 16, 23–41.

Adrimi-Sismani, V., 2007. Mycenaean northern borders revisited: New evidence from Thessaly. *In*: M.L. Galaty and W.A. Parkinson, eds. *Rethinking Mycenaean palaces: new interpretations of an old idea, 2nd edition*. Los Angeles: Cotsen Institute of Archaeology, Universtity of California.

Alcock, S.E., 2002. *Archaeologies of the Greek past: landscape, monuments, and memories*. Cambridge: Cambridge University Press.

Alcock, S.E. and Osborne, R., eds., 1994. *Placing the Gods: Sanctuaries and Sacred Space in Ancient Greece*. Oxford: Clarendon Press.

Aleshire, S.B., 1992. The Economics of Dedication at the Athenian Asklepieion. *In*: T. Linders and B. Alroth, eds. *Economics of Cult in the Ancient Greek World, Proceedings of the Uppsala Symposium 1990*. Uppsala, 85–99.

Alroth, B., 1987. Visiting Gods - Who and Why? *In*: T. Linders and G.C. Nordquist, eds. *Gifts to the Gods, Proceedings of the Uppsala Symposium 1985*. Uppsala, 9–19.

Andronikos, M., 1969. *Vergina I, to nekrotafeio ton tymbon*. Athens.

Angelini, E., Grassini, S., Corbellini, S., Ingo, G.M., De Caro, T., Plescia, P., Riccucci, C., Bianco, A., and Agostini, S., 2006. Potentialities of XRF and EIS portable instruments for the characterisation of ancient artefacts. *Applied Physics A: Materials Science & Processing*, 83, 643–649.

Apostolopoulou-Kakavogianni, O., 1979. Τοπογραφία της Περιοχής των Φερών Θεσσαλίας κατά την Προϊστορική Περίοδο. *AD*, 34: Meletes, 199.

Apostolopoulou-Kakavogianni, O., 1992. Ευρήματα της Πρωτογεωμετρικής και Γεωμετρικής Περιόδου από τις Φερές. *In*: E. Kypraiou, ed. *Διεθνές Συνέδριο για την Αρχαία Θεσσαλία στη Μνήμη του Δημήτρη Ρ. Θεοχάρη (International Conference for Ancient Thessaly in the Memory of D.R. Theocharis)*. Athens: Ministry of Culture, 312–320.

Appadurai, A., ed., 1986a. *The Social Life of Things: Commodities in Cultural Perspective*. Cambridge: Cambridge University Press.

Appadurai, A., 1986b. Introduction: Commodities and Politics of Value. *In*: A. Appadurai, ed. *The Social Life of Things: Commodities in Cultural Perspective*. Cambridge: Cambridge University Press, 3–63.

Arachoviti, P., 1994. Protogeometric tholos tomb at ancient Pherae (in Greek). *In*: B. Helly, ed. *La Thessalie: Quinze Années de Recherches Archéologiques, 1975-1990. Bilans et Perspectives. Actes du Colloque International, Lyon, 17-22 Avril 1990, vol. B.* Athens: Ministry of Culture, 125–138.

Arachoviti, P., 2000. Στοιχεία αρχαιολογικής δράσης στις Φερές και την ευρύτερη περιοχή τους τα τελευταία οκτώ χρόνια. *In*: *Το Έργο των Εφορειών Αρχαιοτήτων και Νεοτέρων Μνημείων του ΥΠ.ΠΟ. στη Θεσσαλία και στην ευρύτερη περιοχή της (1990-1998). 1η Επιστημονική Συνάντηση, Βόλος, Μάιος 1998*. Volos: Ministry of Culture, 355–71.

Arachoviti, P., Doulgeri-Intzesiloglou, A., and Tsigara, M., 2012. Ναός Θαυλίου Διός Φερών. Νέα δεδομένα. *In*: A. Mazarakis Ainian, ed. *Proceedings of the 3rd Archaeological Work in Thessaly and Central Greece*. Volos: Ministry of Culture and Tourism; University of Thessaly, 451–458.

Archibald, Z.H., 2000. Space, Hierarchy, and Community in Archaic and Classical Macedonia, Thessaly, and Thrace. *In*: R. Brock and S. Hodkinson, eds. *Alternatives to Athens: Varieties of Political Organization and Community in Ancient Greece*. Oxford, New York: Oxford University Press, 212–233.

Arvanitopoulos, A.S., 1925. *ΠΑΕ*, 26, 37–42.

Arvanitopoulos, A.S., 1926. Report of Excavations in Pherae, Thessaly, at the Sanctuary of Zeus Thaulios, in year 1925. In: Heffner, E.H., Barton G.A., van Buren, A.W., Rogers, R.W. and E.P.B. Archaeological News. *American Journal of Archaeology*, 30 (1), 96–124.

Asderaki-Tzoumerkioti, E. and Rehren, T., 2006. Hellenistic lead workshop at Pherae (in Greek). *In*: *Hypereia 4*. 79–87.

Aubet Semmler, M.E., 2002. Phoenician trade in the West: balance and perspectives. *In*: M.R. Bierling and S. Gitin, eds. *The Phoenicians in Spain: an archaeological review of the eighth-sixth centuries B.C.E.* USA: Eisenbrauns, 97–112.

Aubry, T., Almeida, F., Araújo, A.C., and Tiffagom, M., eds., 2008. *Space and time: which diachronies, which synchronies, which scales? (Section C64) - Typology vs. technology (Section C65)*. Oxford: Archaeopress.

Balliana, E., Aramendía, M., Resano, M., Barbante, C., and Vanhaecke, F., 2013. Copper and tin isotopic analysis of ancient bronzes for archaeological investigation: development and validation of a suitable analytical methodology. *Analytical and Bioanalytical Chemistry*, 405 (9), 2973–2986.

Balthazar, 1990. *Copper and bronze working in Early through Middle Bronze Age Cyprus*. Jonsered.

Barbiera, I., 2009a. Memory of a better death: conventional and exceptional burial rites in central European cemeteries of the AD 6th and 7th centuries. *In*: I. Barbiera, A.M. Choyke, and J.A. Rasson, eds. *Materializing memory: archaeological material culture and the semantics of the past*. Oxford: Archaeopress, 65–75.

Barbiera, I., 2009b. Introduction. *In*: I. Barbiera, A.M. Choyke, and J.A. Rasson, eds. *Materializing memory: archaeological material culture and the semantics of the past*. Oxford: Archaeopress, 17–19.

Barbiera, I., Choyke, A.M., and Rasson, J.A., eds., 2009. *Materializing memory: archaeological material culture and the semantics of the past*. Oxford: Archaeopress.

Bass, G.F., 1967. Cape Gelidonya: a Bronze Age shipwreck. *Transactions of the American Philosophial Society*, 57 (part 8).

Bass, G.F., 1973. Cape Gelidonya and Bronze Age maritime trade. *In*: H.A. Hoffner, ed. *Orient and Occident: Festshrift Cyrus H. Gordon (Alter Orient und Altes Testament 22)*. Neukirchen, 29–38.

Bass, T., 1991. Land of bronze. *Discover*, 12 (10), 62–66.

Bassiakos, Y. and Philaniotou, O., 2007. Early copper production on Kythnos: archaeological evidence and analytical approaches to the reconstruction of the metallurgical process. *In*: P.M. Day and R.C.P. Doonan, eds. *Metallurgy in the Early Bronze Age Aegean*. Oxford: Oxbow Books, 19–56.

Bayley, J., 1998. The Production of Brass in Antiquity with Particular Reference to Roman Britain. *In*: P.T. Craddock, ed. *2000 Years of Zinc and Brass*. London: British Museum, 7–26.

Beck, L., Bosonnet, S., Réveillon, S., Eliot, D., and Pilon, F., 2004. Silver surface enrichment of silver-copper alloys: a limitation for the analysis of ancient silver coins by surface techniques. *Nuclear Instruments and Methods in Physics Research B*, 226, 153–162.

Begemann, F., Kallas, K., Schmitt-Strecker, S., and Pernicka, E., 1999. Tracing ancient tin via isotope analysis. *In*: A. Hauptmann, E. Pernicka, T. Rehren, and Ű. Yalçin, eds. *The beginnings of metallurgy*. Bochum: Deutsches Bergbau-Museum, 277–284.

Begemann, F., Schmitt-Strecker, S., and Pernicka, E., 1989. Isotopic composition of lead in early metal artefacts: results, possibilities and limitations. *In*: A. Hauptmann, E. Pernicka, and G.A. Wagner, eds. *Old World Archaeometallurgy*. Bochum: Deutsches Bergbau-Museum, 269–278.

Benton, S., 1964. In: Notes and News. *Antiquity*, 38, 138.

Benvenuti, M., Chiarantini, L., Norfini, A., Casini, A., Guideri, S., and Tanelli, G., 2003. The Etruscan tin: a preliminary contribution from researchers at Monte Valerio and Baratti-Populonia (Southern Tuscany, Italy). *In*: A. Giumlia-Mair and F. Lo Schiavo, eds. *The Problem of Early Tin*. Oxford: Archaeopress, 55–66.

Béquignon, Y., 1937. *Recherches archéologiques à Phères de Thessalie*. Paris: Les Belles Lettres.

Bergman, J., 1987. Religio-phenomenological Reflections on the Multi-level Process of Giving to the Gods. *In*: T. Linders and G.C. Nordquist, eds. *Gifts to the Gods, Proceedings of the Uppsala Symposium 1985*. Uppsala, 31–42.

Bernard, M.C. and Joiret, S., 2009. Understanding corrosion of ancient metals for the conservation of cultural heritage. *Electrochimica Acta*, 5199–5205.

Bernardini, P., 2010. Le torri, i metalli, il mare. Storie antiche di un'isola mediterranea. *Sardegna Archeologica. Scavi e ricerche*, 6.

Betancourt, P.P., ed., 2006. The chrysokamino metallurgy workshop and its territory. *Hesperia*, Supplement 36.

Betancourt, P.P., Muhly, J.D., Farrand, W.R., Searns, C., Onyshkevych, L., Hafford, W.B., and Evely, D., 1999. Research and excavation at Chrysocamino, Crete 1995-1998. *Hesperia*, 68 (3), 343–370.

Birmingham, J.M., 1961. The Overland Route across Anatolia in the Eighth and Seventh Centuries B.C. *Anatolian Studies*, 11, 185–195.

Blake, E., 2005. The material expression of cult, ritual, and feasting. *In*: E. Blake and A.B. Knapp, eds. *The Archaeology of Mediterranean Prehistory*. Oxford: Blackwell, 102–129.

Blinkenberg, C., 1926. *Fibules Grecques et Orientales*. Copenhagen: A.F. Høst and Son.

Bond, G.C. and Gilliam, A., eds., 1994. *Social construction of the past: representation as power*. London: Routledge.

Boni, M. and Ippolito, F., 1976. Provenienza dei metalli per la monetazione Etrusca. *In*: *Contributi introduttivi allo studio della monetazione Etrusca. Atti del V Convegno del Centro Internazionale di Studi Numismatici, Napoli Aprile 1975*. Rome: Instituto Italiano di Numismatica.

Bosi, C., Gargnani, G.L., Imbeni, V., Martini, C., Mazzeo, R., and Poli, G., 2002. Unalloyed copper inclusions in ancient bronze artefacts. *Journal of Materials Science*, 37, 4285–4298.

Bouzek, J., 1967. Die griechisch-geometrischen Bronzevögel. *Eirene*, 6, 115–139.

Bouzek, J., 1969. *Homerisches Griechenland*. Prague.

Bouzek, J., 1974. *Graeco-Macedonian Bronzes: Analysis and Chronology*. Prague.

Bouzek, J., 1985. The Aegean, Anatolia and Europe: Cultural interrelations in the second millennium BC. *Studies in Mediterranean Archaeology*, 28-29.

Bouzek, J., 1988. Macedonian and Thessalian Bronzes. *Archaeologiki Efimeris*, 47–60.

Bouzek, J., 1997. Greece, Anatolia and Europe: Cultural interrelations during the Early Iron Age. *Studies in Mediterranean Archaeology*, 122.

Bowersock, G.W., 1965. Zur Geschichte des römischen Thessaliens. *Rheinsches Museum für Philologie*, 108 (3), 277–89.

Bowman, R., Friedman, A.M., Lerner, J., and Milsted, J., 1975. A statistical study of the impurity occurrences in copper ores and their relationship to ore types. *Archaeometry*, 17, 157–164.

Bradley, R., 1982. The Destruction of Wealth in Later Prehistory. *Man*, 17 (1), 108–122.

Branigan, K., 1982. Minoan metallurgy and Cypriot copper. *In*: J. Muhly, R. Maddin, and V. Karageorghis, eds. *Acta of the International Archaeological Symposium 'Early Metallurgy in Cyprus 4000-500 BC, Larnaca, Cyprus, 1-6 June 1981*. Nicosia, 203–211.

Du Bray, E.A., 1985. Geology of the Silsilah ring complex, and associated tin mineralization, Kingdom of Saudi Arabia - a synopsis. *American Mineralogist*, 70, 1075–1086.

Bray, P.J. and Pollard, A.M., 2012. A new interpretative approach to the chemistry of copper-alloy objects: source, recycling and technology. *Antiquity*, 86, 853–867.

Bremer, J.-M., 1998. The Reciprocity of Giving and Thanksgiving in Greek Worship. *In*: C. Gill, N. Postlethwaite, and R. Seaford, eds. *Reciprocity in Ancient Greece*. Oxford: Oxford University Press, 127–137.

Brize, P., 1988. In: General Discussion on Votive Offerings. *In*: N. Marinatos, R. Hägg, and G.C. Nordquist, eds. *Early Greek Cult Practice*. 222.

Bruno, A. and Kostoglou, M., 2012. Object life-cycles, edge-wear analysis and the study of ancient metal artefacts. *In*: A. Kordas and L. Filippaki, eds. *History, technology and conservation of ancient metals, glasses and enamels*. Athens: National Centre of Scientific Research Demokritos.

Brussell, D.E., 2004. Medicinal Plants of Mt. Pelion, Greece. *Economic Botany*, 58 (Supplement), S174–S202.

Budd, P., Haggerty, R., Pollard, A.M., Scaife, B., and Thomas, R.G., 1995. New heavy isotope studies in archaeology. *Israel Journal of Chemistry*, 35, 125–130.

Budd, P., Haggerty, R., Pollard, A.M., Scaife, B., and Thomas, R.G., 1996. Rethinking the quest for provenance. *Antiquity*, 70, 168–174.

Burkert, W., 1983a. Itinerant Diviners and Magicians: A Neglected Element in Cultural Contacts. *In*: R. Hägg, ed. *The Greek Renaissance of the Eighth Century BC: Tradition and Innovation*. Stockholm: Paul Åströms Förlag, 115–119.

Burkert, W., 1983b. *Homo necans: the anthropology of ancient Greek sacrificial ritual and myth*. Berkeley, London: University of California Press.

Burkert, W., 1987. Offerings in Perspective: Surrender, Disribution, Exchange. *In*: T. Linders and G.C. Nordquist, eds. *Gifts to the Gods, Proceedings of the Uppsala Symposium 1985*. Uppsala, 43–50.

Caley, E.R., 1949. Klaproth as a Pioneer in the Chemical Investigation of Antiquities. *Journal of Chemical Education*, 26 (4), 242–268.

Caley, E.R., 1951. Early history and literature of archaeological chemistry. *Journal of Chemical Education*, 28, 64–66.

Caley, E.R., 1964. *Analysis of Ancient Metals*. London: Pergamon Press.

Caley, E.R., 1967. The early history of chemistry in the service of archaeology. *Journal of Chemical Education*, 44 (3), 120–123.

Cambi, L., 1959. Problemi della metallurgia. *Etrusca Studi Etruschi*, 415–432.

Carter, G.F., 1977. Reproducibility of X-ray fluorescence analyses of septimus severus denarii. *Archaeometry*, 19 (1), 67–73.

Carter, G.F., Caley, E.R., Carlson, J.H., Carriveau, G.W., Hughes, M.J., Rengan, K., and Segebade, C., 1983. Comparison of analyses of eight Roman orichalcum coin fragments by seven methods. *Archaeometry*, 25 (2), 201–213.

Carter, J.B., 1998. Egyptian bronze jugs from Crete and Lefkandi. *JHS*, 118, 172–177.

Cathro, R.J., 2005. Tin Deposits and the Early History of Bronze. *CIM Magazine*, 98.

Catling, H.W. and Jones, R.E., 1976. The analyses of some recently excavated bronzes from Knossos, Sparta and Nichoria. *In*: *Archaeometry Conference*. Edinburgh.

Cesareo, R., Bustamante, A., Fabian, J., Calza, C., Dos Anjos, M., Lopes, R.T., Alva, W., and Seclen, M., 2011. Portable equipment for a non-destructive analysis of pre-Columbian metal artefacts from the Royal Tombs of Sipán by energy-dispersive X-ray fluorescence spectrometry. *X-Ray Spectrometry*, 40 (1), 37–46.

Chapman, J., 2009. Notes on memory-work and materiality. *In*: I. Barbiera, A.M. Choyke, and J.A. Rasson, eds. *Materializing memory: archaeological material culture and the semantics of the past*. Oxford: Archaeopress, 7–16.

Chapman, R., 1996. 'Inventiveness and Ingenuity'? Craft Specialization, Metallurgy, and the West Mediterranean Bronze Age. *In*: B. Wailes, ed. *Craft Specialization and Social Evolution: In Memory of V. Gordon Childe*. Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology, 73–84.

Charalambous, A., Kassianidou, V., and Papassavas, G., 2014. A compositional study of Cypriot bronzes dating to the Early Iron Age using portable X-ray fluorescence spectrometry (pXRF). *Journal of Archaeological Science*, 46, 205–216.

Charles, J.A., 1973. Heterogeneity in Metals. *Archaeometry*, 15, 105–114.

Charles, J.A., 1978. The development of the usage of tin and tin-bronze: some problems. *In*: A.D. Franklin, J.S. Olin, and T.A. Wertime, eds. *The Search for Ancient Tin*. Washingtong D.C.: Smithsonian Museum, 25–32.

Charles, J.A., 1980. The Coming of Copper and Copper-Base Alloys and Iron: A Metallurgical Sequence. *In*: A. Wertime and J.D. Muhly, eds. *The Coming of the Age of Iron*. New Haven and London: Yale University Press, 151–181.

Chesson, M.S., 2001. Embodied memory of place and people: death and society in an early urban community. *Archaeological Papers of the American Anthropological Association*, 10, 100–113.

Chikwendu, V.E., Craddock, P.T., Farquhar, R.M., and Shaw, T., 1989. Nigerian sources of copper, lead and tin for the Igbo-Ukwu bronzes. *archaeometry*, 31 (1), 27–36.

Chrysostomou, A., 2007. Part III. Agrosykia. The Early Iron Age settlement and cemeteries. *In*: P. Chrysostomou, I. Alsanis, and A. Chrysostomou, eds. *Agrosykia: a prehistoric and historic settlement (in Greek)*. Veroia: Institute of Greek and Roman Antiquity, 209–279.

Chrysostomou, P., 1983. Το Πανδοχείο και το Διοσκουρείο των Φερών. *AAA*, 16, 95–105.

Chrysostomou, P., 1994a. Η Λατρεία του Διονύσου στη Θεσσαλία και ειδικότερα στις Φερές. *In*: D. Karamberopoulos and E. Kakavogiannis, eds. *Hypereia 2, vol. 1*. 113–139.

Chrysostomou, P., 1994b. Εν(ν)οδία, Ενοδία Εκάτη, Εκάτη Ενοδία. *In*: B. Helly, ed. *La Thessalie: Quinze Années de Recherches Archéologiques, 1975-1990. Bilans et Perspectives. Actes du Colloque International, Lyon, 17-22 Avril 1990, vol. B.* Athens: Ministry of Culture, 339–346.

Chrysostomou, P., 1998. *Η Θεσσαλική Θεά Εν(ν)οδία ή Φεραία Θεά*. Athens: Ministry of Culture.

Chrysostomou, P., 2008. Η Μεγάλη Θεά Εν(ο)δία.

Clement, P.A., 1932. The Cults of Pherae and the Artemis Pheraea Goddess. In: General Meeting of the Archaeological Institute of America December 29-31, 1931. *American Journal of Archaeology*, 36 (1), 36–42.

Clement, P.A., 1939. A Note on the Thessalian Cult of Enodia. *Hesperia*, 8 (2), 200.

Cline, E.H., 2014. *1177 BC: the year civilization collapsed*. Princeton, NJ: Princeton University Press.

Cockrell, B., Ruvalcaba Sil, J.L., and Ortiz Díaz, E., 2014. For whom the bells fall: metals from the Cenote Sagrado, Chichén Itzà. *Archaeometry*, online.

Cohen, B., ed., 1995. *The distaff side. Representing the female in Homer's Odyssey*. Oxford, New York: Oxford University Press.

Coldstream, J.N., 1983a. Gift Exchange in the Eighth Century BC. *In*: R. Hägg, ed. *The Greek Renaissance of the Eighth Century BC: Tradition and Innovation*. Stockholm: Paul Åströms Förlag, 201–207.

Coldstream, J.N., 1983b. In: General Discussion on Metal Votives and Metal Working. *In*: R. Hägg, ed. *The Greek Renaissance of the Eighth Century BC: Tradition and Innovation*. Stockholm: Paul Åströms Förlag, 165.

Coldstream, J.N., 2003. *Geometric Greece (900-700 BC)*. London and NY: Routledge.

Cook, A.B., 1925. *Zeus. A Study in Ancient Religion. Volume II, part II*. Cambridge: Cambridge University Press.

Cooke, S.R.B. and Aschenbrenner, S., 1975. The occurrence of metallic iron in ancient copper. *Journal of Field Archaeology*, 2, 251–266.

Cosmopoulos, M.B., 2014. Cult, continuity, and social memory: Mycenaean Eleusis and the transition to the Early Iron Age. *American Journal of Archaeology*, 118 (3), 401–427.

Costin, C.L., 2005. Craft Production. *In*: H.D.G. Maschner and C. Chippindale, eds. *Handbook of Archaeological Methods*. New York: Altamira Press, 1034–1107.

Costin, C.L. and Hagstrum, M.B., 1995. Standardization, labor investment, skill and the organization of ceramic production in Late Prehispanic Highland Peru. *American Antiquity*, 60 (4), 619–39.

Coulmas, F., 2003. *Writing Systems: an introduction to their linguistic analysis*. Cambridge: Cambridge University Press.

Coulton, J., 1993. The Toumba Building: Description and Analysis of the Architecture. *In*: M.R. Popham, P.G. Calligas, and L.H. Sackett, eds. *Lefkandi II: the Protogeometric Building at Toumba, Part 2. The Excavation, Architecture and Finds.* Oxford: BSA Suppl. vol. 23, 33–70.

Craddock, P.T., 1976. The Composition of the Copper Alloys used by the Greek, Etruscan and Roman Civilizations: 1. The Greeks before the Archaic Period. *Journal of Archaeological Science*, 3, 93–113.

Craddock, P.T., 1977. The Composition of the Copper Alloys used by the Greek, Etruscan and Roman Civilizations: 2. The Archaic, Classical and Hellenistic Greeks. *Journal of Archaeological Science*, 4, 103–23.

Craddock, P.T., 1978. The Composition of the Copper Alloys used by the Greek, Etruscan and Roman Civilizations: 3. The Origins and Early Use of Brass. *Journal of Archaeological Science*, 5, 1–16.

Craddock, P.T., 1980. The composition of copper produced at the ancient smelting camps in the Wadi Timna, Israel. *In*: P.T. Craddock, ed. *Scientific studies in early mining and extractive metallurgy*. London: British Museum, 165–175.

Craddock, P.T., 1995. *Early Metal Mining and Production*. Edinburgh: Edinburgh University Press.

Craddock, P.T., 1998. Zinc in Classical Antiquity. *In*: P.T. Craddock, ed. *2000 Years of Zinc and Brass*. London: British Museum, 1–6.

Craddock, P.T. and Eckstein, K., 2003. Production of brass in antiquity by direct reduction. *In*: P.T. Craddock and J. Lang, eds. *Mining and Metal Production through the Ages*. London: The British Museum Press, 216–230.

Craddock, P.T. and Meeks, N.D., 1987. Iron in Ancient Copper. *Archaeometry*, 29 (2), 187–204.

Crawford, S., 2004. Votive Deposition, Religion and the Anglo-Saxon Furnished Burial Ritual. *World Archaeology*, 36 (1), 87–102.

Çukur, A. and Kunç, S., 1989. Development of bronze production technologies in Anatolia. *Journal of Archaeological Science*, 16 (3), 225–231.

Curta, F., 2005. Female Dress and ‘Slavic’ Bow Fibulae in Greece. *Hesperia*, 74 (1), 101–146.

Damaskos, D. and Plantzos, D., eds., 2008. *A singular antiquity: archaeology and Hellenic identity in twentieth-century Greece*. Athens: Benaki Museum.

Damgaard Andersen, H., Horsæs, H.W., and Houby-Nielsen, S., 1997. Introduction. *In*: H. Damgaard Andersen, H.W. Horsæs, S. Houby-Nielsen, and A. Rathje, eds. *Urbanization in the Mediterranean in the 9th to 6th centuries BC*. Copenhagen: Museum Tusculanum Press, 9–15.

Davenport, W.H., 1986. Two Kinds of Value in the Eastern Solomon Islands. *In*: A. Appadurai, ed. *The Social Life of Things: Commodities in Cultural Perspective*. Cambridge: Cambridge University Press, 95–109.

Davies, O., 1929. Two north Greek mining towns. *JHS*, 49, 89–99.

Davies, O., 1934. The Chemical Composition of Archaic Greek Bronzes. *BSA*, 35, 131–137.

Davy, J., 1826. Observations on the changes which have taken place in some ancient alloys of copper. *Philosophical Transactions of the Royal Society*, 116, 55–59.

DeMarrais, E., 2013. Understanding heterarchy: crafting and social projects in Pre-Hispanic Northwest Argentina. *Cambridge Archaeological Journal*, 23 (3), 345–362.

DeMarrais, E., Gosden, C., and Renfrew, C., eds., 2005. *Rethinking materiality*. Cambridge: McDonald Archaeological Institute.

Desborough, V.R. d’A., 1972. *The Greek Dark Ages*. London: Ernest Ben Ltd.

Dickinson, O., 1994. *The Aegean Bronze Age*. Cambridge: Cambridge University Press.

Dickinson, O., 2006a. *The Aegean from Bronze Age to Iron Age. Continuity and change between the 12th and 8th c. BC*. London and NY: Routledge.

Dickinson, O., 2006b. The Mycenaean Heritage of Early Iron Age. *In*: S. Deger-Jalkotzy and I. Lemos, eds. *Ancient Greece: from the Mycenean palaces to the Age of Homer*. Edinburgh: Edinburgh University Press, 115–122.

Dietrich, B.C., 1983. Tradition in Greek Religion. *In*: R. Hägg, ed. *The Greek Renaissance of the Eighth Century BC: Tradition and Innovation*. Stockholm: Paul Åströms Förlag, 85–90.

Dobres, M.-A., 2000. *Technology and Social Agency: Outlining a Practice Framework for Archaeology*. Oxford: Blackwell.

Dobres, M.-A. and Robb, J.E., eds., 2000. *Agency in Archaeology*. London and NY: Routledge.

Donald, M., 1991. *Origins of the modern mind: three stages in the evolution of culture and cognition*. Cambridge, Massachusetts: Harvard University Press.

Donald, M., 1993. Précis of origins of the modern mind: three stages in the evolution of culture and cognition. *Behavioural and Brain Sciences*, 16, 737–748.

Donald, M., 1998. Material culture and cognition: concluding thoughts. *In*: C. Renfrew and C. Scarre, eds. *Cognition and Material Culture: the Archaeology of Symbolic Storage*. Cambridge: McDonald Archaeological Institute, 181–187.

Donlan, W., 1989. The pre-state community in Greece. *Symbolae Osloenses*, 64, 18–21.

Donovan, J.J., 2011. High sensitivity EPMA: past, present and future. *Microscopy and Microanalysis*, 17 (Suppl 2), 560–561.

Doulgeri-Intzesiloglou, A., 1992. Hellenistic pottery workshops at the ancient city of Pherae (in Greek). *In*: E. Kypraiou, ed. *International Conference for Ancient Thessaly in the Memory of D.R. Theocharis*. Athens: Ministry of Culture, 437–447.

Doulgeri-Intzesiloglou, A., 1994. New archaeological research at ancient Pherae (in Greek). *In*: B. Helly, ed. *La Thessalie: Quinze Années de Recherches Archéologiques, 1975-1990. Bilans et Perspectives. Actes du Colloque International, Lyon, 17-22 Avril 1990, vol. B.* Athens: Ministry of Culture, 71–92.

Doulgeri-Intzesiloglou, A., 2000. Pherae-Peparithos-Skiathos: eight years of archaeological work (1990-1998) (in Greek). *In*: *Το έργο των Εφορειών Αρχαιοτήτων και Νεότερων Μνημείων του ΥΠΠΟ στη Θεσσαλία και την ευρύτερη περιοχή της (1990-1998). 1η Επιστημονική Συνάντηση*. Volos: Ministry of Culture, 345–353.

Doulgeri-Intzesiloglou, A., 2006. Archaeological museum of Pherae-Velestino: a museological study (in Greek). *In*: *Hypereia 4*. 89–109.

Doulgeri-Intzesiloglou, A. and Arachoviti, P., 2006. Η αρχαία πόλη των Φερών. Πορίσματα ερευνών της τελευταίας εικοσιπενταετίας (1980-2005). *In*: *Πρακτικά 1ου Διεθνούς Συνεδρίου Ιστορίας και Πολιτισμού της Θεσσαλίας, Λάρισα, Τομ. Ι*. 232–243.

Drews, R., 1993. *Changes in warfare and the catastrophe ca. 1200 BC*. Princeton, NJ: Princeton University Press.

Dungworth, D., 2000. A note on the analysis of crucibles and moulds. *Historical Metallurgy*, 34, 83–86.

Dussubieux, L., Deraisme, A., Frot, G., Stevenson, C., Creech, A., and Bienvenu, Y., 2008. LA-ICP-MS, SEM-EDS and EPMA analysis of eastern North American copper-based artefacts: impact of corrosion and heterogeneity of the reliability of the LA-ICP-MS compositional results. *Archaeometry*, 50 (4), 643–657.

Dussubieux, L., Pinchin, S.E., Tsang, J.S., and Tumosa, C.S., 2005. Non-destructive elemental analysis: reliability of a portable X-ray fluorescence spectrometer for museum applications. *In*: *Preprints of the 14th Triennial Meeting, The Hague, 12-16 September 2005*. ICOM-CC, 766–773.

Earl, B. and Adriaens, A., 2000. Initial experiments on arsenical bronze production. *Journal of Minerals, Metals and Materials Society*, 52 (3), 14–16.

Earl, B. and Özbal, H., 1996. Early Bronze Age tin processing at Kestel/Göltepe, Anatolia. *Archaeometry*, 38 (2), 289–303.

Eder, B., 2001a. Continuity of Bronze Age cult at Olympia? The evidence of the Late Bronze Age and Early Iron Age Pottery. *In*: R. Laffineur and R. Hägg, eds. *Potnia. Deities and religion in the Aegean Bronze Age. Proceedings of the 8th International Aegean Conference, Göteborg, Göteborg University, 12-15 April 2000*. Liège; Austin: Université de Liège, Histoire de l'art et archéologie de la Grèce antique; University of Texas at Austin, Program in Aegean Scripts and Prehistory, 201–209.

Eder, B., 2001b. *Die submykenischen und protogeometrischen Gräber von Elis*. Archäologische Gesellschaft zu Athen.

Englund, G., 1987. Gifts to the Gods - a Necessity for the Preservation of Cosmos and Life. Theory and Practice. *In*: T. Linders and G.C. Nordquist, eds. *Gifts to the Gods, Proceedings of the Uppsala Symposium 1985*. Uppsala, 57–66.

Erdman, K.M., 2012. Votives and value: communicating with the supernatural. *In*: A. Bokern and C. Rowan, eds. *Embodying value? The transformation of objects in and from the ancient world*. Oxford: Archaeopress, 89–100.

Fabrizi, M. and Scott, D.A., 1987. Unusual Copper Corrosion Products and Problems of Identity. *In*: J. Black, ed. *Recent Advances in the Conservation and Analysis of Artifacts*. London: Summer School Press, 131–133.

Fang, J.L. and McDonnell, J.G., 2011. The colour of copper alloys. *Historical Metallurgy*, 45 (1), 52–61.

Fantalkin, A., 2006. Identity in the Making: Greeks in the Eastern Mediterranean during the Iron Age. *In*: A. Villing and U. Schlotzhauer, eds. *Naukratis: Greek Diversity in Egypt. Studies on East Greek Pottery and Exchange in the Eastern Mediterranean*. London: British Museum, 199–235.

Farnsworth, M., Smith, C.S., and Rodda, J.L., 1949. Metallographic examination of a sample of metallic zinc from ancient Athens. *Hesperia*, Suppl. 8, 126–9.

Farquhar, R.M. and Vitali, V., 1989. Lead isotope measurements and their application to Roman lead and bronze artifacts from Carthage. *In*: S.J. Fleming and H.R. Schneck, eds. *History of Technology: The Role of Metals*. Philadelphia: MASCA, The University Museum, University of Pennsylvania, 39–45.

Felsch, R.C.S., 1983. Zur Chronologie and zum Stil geometrischer Bronzen aus Kalapodi. *In*: R. Hägg, ed. *The Greek Renaissance of the Eighth Century BC: Tradition and Innovation*. Stockholm: Paul Åströms Förlag, 123–129.

Felsch, R.C.S., ed., 2007. *Kalapodi. Ergebnisse der Ausgrabungen im Heiligtum der Artemis und des Apollon von Hyampolis in der antiken Phokis. Band II*. Mainz am Rhein: Philipp von Zabern.

Fentress, J. and Wickham, C., 1992. *Social memory*. ox: Blackwell.

Ferretti, M., Miazzo, L., and Moioli, P., 1997. The application of a nondestructive XRF method to identify different alloys in the bronze statue of the Capitoline Horse. *Studies in Conservation*, 42 (4), 241–246.

Ferretti, M. and Moioli, P., 1998. The use of portable XRF systems for preliminary compositional surveys on large bronze objects. A critical review after some years' experience. *In*: W. Mourey and L. Robbiola, eds. *Proceedings of the International Conference Metal 98*. 39–44.

Feuer, B., 1983. *The northern Mycenaean border in Thessaly*. Oxford: Archaeopress.

Feuer, B., 1994. Mycenaean Thessaly. *In*: B. Helly, ed. *La Thessalie: Quinze Années de Recherches Archéologiques, 1975-1990. Bilans et Perspectives. Actes du Colloque International, Lyon, 17-22 Avril 1990*. Athens: Ministry of Culture, 211–214.

Field, A., 2009. *Discovering statistics using SPSS*. 3rd ed. London: SAGE.

Forbes, R.J., 1964. *Studies in Ancient Technology, VIII*. Leiden.

Forster, N., Grave, P., Vickery, N., and Kealhofer, L., 2011. Non-destructive analysis using PXRF: methodology and application to archaeological ceramics. *X-Ray Spectrometry*, 40 (5), 389–398.

Frahm, E., 2013a. Validity of 'off-the-shelf' handheld protable XRF for sourcing Near Eastern obsidian chip debris. *Journal of Archaeological Science*, 40 (2), 1080–1092.

Frahm, E., 2013b. Is obsidian sourcing about geochemistry or archaeology? A reply to Speakman and Shackley. *Journal of Archaeological Science*, 40 (2), 1444–1448.

Frahm, E. and Doonan, R.C.P., 2013. The technological versus methodological revolution of portable XRF in archaeology. *Journal of Archaeological Science*, 40 (2), 1425–1434.

Frank, A.G., Algaze, G., Barcelo, J.A., Chase-Dunn, C., Edens, C., Friedman, J., Gilman, A., Gosden, C., Harding, A.F., Joffe, A.H., Knapp, A.B., Kohl, P.L., Kristiansen, K., Lamberg-Karlovsky, C.C., McNeill, J.R., Muhly, J.D., Sherratt, A., and Sherratt, S., 1993. Bronze Age world system cycles [and comments and reply]. *Current Anthropology*, 34 (4), 383–429.

Franklin, A.D., Olin, J.S., and Wertime, T.A., eds., 1978. *The Search for Ancient Tin*. Washingtong D.C.: Smithsonian Institution Press.

Gale, N.H., 1990. The provenance of metals for EBA Crete - local or Cycladic? *In*: *Πεπραγμένα του ΣΤ' Διεθνούς Κρητολογικού Συνεδρίου 1*. Chania, Greece, 299–316.

Gale, N.H., 1997. The isotopic composition of tin in some ancient metals and the recycling problem in metal provenancing. *Archaeometry*, 39, 71–82.

Gale, N.H., Kayafa, M., and Stos-Gale, Z., 2009. Further Evidence for Bronze Age Production of Copper from Ores in the Lavrion Ore District, Attica, Greece. *In*: *Proceedings of the 2nd International Conference Archaeometallurgy in Europe, Aquileia, 17-21 June 2007*. Milan, 158–176.

Gale, N.H., Papastamataki, A., Stos-Gale, Z., and Leonis, K., 1985. Copper sources and copper metallurgy in the Aegean Bronze Age. *In*: P.T. Craddock and M.J. Hughes, eds. *Furnaces and Smelting Technology in Antiquity*. London: British Museum, 81–101.

Gale, N.H. and Stos-Gale, Z., 1982. Bronze Age Copper Sources in the Mediterranean: a new approach. *Science*, 216, 11–19.

Gale, N.H. and Stos-Gale, Z., 1986. Oxhide copper ingots in Crete and Cyprus and the Bronze Age metals trade. *BSA*, 81, 81–100.

Gale, N.H. and Stos-Gale, Z., 2008. Changing patterns in prehistoric Cycladic metallurgy. *In*: C. Renfrew, N. Brodie, and D. Kemp, eds. *Proceedings of the Cambridge Colloquium on the Prehistory of Cyclades*. Cambridge, 427–447.

Gallis, K., 1996. Central and Western Thessaly. *In*: G.A. Papathanassopoulos, ed. *Neolithic Culture in Greece*. Athens: Goulandris Foundation, 61–66.

García Ramón, J.J. and Helly, B., 2007. Εννοδία Κορουταρρα («celle qui dote de nourriture, de croissance») et autres divinités kourotrophes en Thessalie. *Revue de Philologie, de Littérature et d'Histoire Anciennes*, 81 (2), 291–312.

Geçkinli, A.E., Bozkurt, N., and Basaran, S., 1986. Metallorgraphic studies of archaeological metal artifacts from Çavustepe. *Aksay Ünitesī Bilimsel Toplanti Bildinileri*, 1, 229–246.

Gell, A., 1998. *Art and Agency: towards a new anthropological theory*. Oxford: Clarendon Press.

Georgakopoulou, M., 2007. The metallurgical remains. *In*: C. Renfrew, C.D. Doumas, L.I. Marangou, and G. Gavalas, eds. *Keros, Dhaskalio Kavos: the investigations of 1987-88*. Cambridge: McDonald Institute for Archaeological Research, 380–401.

Georgakopoulou, M., Bassiakos, Y., and Philaniotou, O., 2011. Seriphos Surfaces: A Study of Copper Slag Heaps and Copper Sources in the Context of Early Bronze Aegean Metal Production. *Archaeometry*, 53 (1), 123–145.

Georganas, I., 2000. Early Iron Age tholos Tombs in Thessaly (c. 1100-700 BC). *Mediterranean Archaeology*, 13, 47–54.

Georganas, I., 2002. Constructing identities in Early Iron Age Thessaly: the case of the Halos tumuli. *Oxford Journal of Archaeology*, 21 (3), 289–298.

Georganas, I., 2005. Weapons and Warfare in Early Iron Age Thessaly. *Mediterranean Archaeology and Archaeometry*, 5 (2), 63–74.

Georganas, I., 2008. Between Admetus and Jason: Pherai in the Early Iron Age. *In*: C. Gallou, M. Georgiadis, and G.M. Muskett, eds. *Dioskouroi. Studies Presented to W. G. Cavanagh and C. B. Mee on the Anniversary of their 30-year Joint Contribution to Aegean Archaeology*. Oxford: Archaeopress.

Georganas, I., 2009. Dying in Early Iron Age Thessaly. *In*: *Arxaiologiko Ergo Thessalias kai Stereas Elladas 2, vol II: Thessalia*. Volos: Ministry of Culture, 195–205.

Gerwin, W., Scharff, W., and Baumhauer, R., 1998. Corrosive Decay of Archaeological Metal Finds from Different Soils and Effects of Environmental Pollution. *In*: W. Mourey and L. Robbiola, eds. *Metal 98*. London: James and James, 100–105.

Gianoncelli, A. and Kourousias, G., 2007. Limiations of portable XRF implementations in evaluating depth information: an archaeometric perspective. *Applied Physics A: Materials Science & Processing*, 89, 857–863.

Gitler, H. and Ponting, M.J., 2006. Chemical analysis of Medieval Islamic coin dies. *The Numismatic Chronicle*, 166, 321–326.

Gitler, H., Ponting, M.J., and Tal, O., 2008. Metallurgical analysis of southern Palestinian coins of the Persian period. *Israel Numismatic Research*, 3, 13–27.

Giumlia-Mair, A., 2005a. Tin rich layers on ancient copper based objects. *Surface Engineering*, 21 (5-6), 359–367.

Giumlia-Mair, A., 2005b. On surface analysis and archaeometallurgy. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, 239 (1), 35–43.

Giumlia-Mair, A. and Lo Schiavo, F., eds., 2003. *The Problem of EarlyTin*. Oxford: Archaeopress.

Godelier, M., 1996. *L' énigme du don*. Paris: Fayard.

Le Goff, J., 1992. *History and memory*. New York: Columbia University Press.

Goffer, Z., 2007. *Archaeological Chemistry*. 2nd ed. New Jersey: John Wiley & Sons.

Goldstein, J., Newbury, D., Joy, D., Lyman, C., Echlin, P., Lifshin, E., Sawyer, L., and Michael, J., 2003. *Scanning Electron Microscopy and X-Ray microanalysis*. 3rd ed. USA: Springer.

Goodale, N., Bailey, D.G., Jones, G.T., Prescott, C., Scholz, E., Stagliano, N., and Lewis, C., 2012. pXRF: a study of inter-instrument performance. *Journal of Archaeological Science*, 39, 875–883.

Gosden, C. and Marshall, Y., 1999. The cultural biography of objects. *World Archaeology*, 31 (2), 169–178.

Gounaris, A.P., 2009. Οικιστική της Θεσσαλίας κατά την Πρωτογεωμετρική-Γεωμετρική Περίοδο: ένας απολογισμός. *In*: A. Mazarakis Ainian, ed. *Archaiologiko ergo Thessalias kai stereas Helladas 2, 2006 : praktika epistēmonikēs synantēsēs, Volos 16.3-19.3.2006*. Volos: YPPO, University of Thessaly, 163–194.

Graninger, D., 2011. *Cult and Koinon in Hellenistic Thessaly*. Leiden; Boston: Brill.

Greco, G., 2008. Introduzione. *In*: G. Greco and B. Ferrara, eds. *Doni agli Dei: il sistema dei doni votivi nei santuari. Atti del seminario di studi, Napoli 21 aprile 2006*. Napoli: Naus, 7–9.

Gregory, C.A., 1980. Gifts to Men and Gifts to God: Gift Exchange and Capital Accumulation in Contemporary Papua. *Man*, 15 (4), 626–652.

Gregory, C.A., 1982. *Gifts and Commodities*. London.

Hägg, R., ed., 1983. *The Greek Renaissance of the Eighth Century BC: Tradition and Innovation*. Stockholm: Paul Åströms Förlag.

Hägg, R., 1987. Gifts to the Heroes in Geometric and Archaic Greece. *In*: T. Linders and G.C. Nordquist, eds. *Gifts to the Gods, Proceedings of the Uppsala Symposium 1985*. Uppsala, 93–99.

Hägg, R., 1992. Sanctuaries and Workshops in the Bronze Age Aegean. *In*: T. Linders and B. Alroth, eds. *Economics of Cult in the Ancient Greek World, Proceedings of the Uppsala Symposium 1990*. Uppsala, 29–32.

Hägg, R., Marinatos, N., and Nordquist, G.C., eds., 1988. *Early Greek Cult Practice, Proceedings of the 5th International Symposium at the Swedish Institute at Athens, 26-29 June, 1986*. Stockholm: Paul Åströms Förlag.

Hall, 1960. X-ray fluorescence analysis applied to archaeology. *Archaeometry*, 3 (1), 29–37.

Hall, J.M., 1997. *Ethnic identity in Greek antiquity*. Cambridge: Cambridge University Press.

Hall, M.E. and Steadman, S.R., 1991. Tin and Anatolia: another look. *Journal of Mediterranean Archaeology*, 4, 217–234.

Halleux, R., 1973. L'orichalque et le laiton. *Antique Classique*, 42, 64–81.

Hamilakis, Y., 2013. *Archaeology of the senses: human experience, memory, and affect*. Cambridge: Cambridge University Press.

Hammond, N.G.L., 1931. Prehistoric Epirus and the Dorian Invasion. *BSA*, 32, 131–179.

Hansen, H.D., 1933. *Early Civilization in Thessaly*. Baltimore: The Johns Hopkins Press.

Haruyama, Y., Saito, M., Mitani, M., Yamamoto, R., and Yoshida, K., 1999. Comparison between PIXE and XRF for old Japanese copper coin analysis. *International Journal of PIXE*, 9, 181–188.

Hastings, J., ed., 1908. *Encyclopædia of Religion and Ethics*. Edinburgh: T. & T. Clark; New York: C. Scribner's Sons.

Haustein, M., Gillis, C., and Pernicka, E., 2010. Tin isotopy - a new method for solving old questions. *Archaeometry*, 52 (5), 816–832.

He, L., Liang, J., Zhao, X., and Jiang, B., 2011. Corrosion behavior and morphological features of archaeological bronze coins from ancient China. *Microchemical Journal*, 99, 203–2012.

Hedges, E.S., 1960. *Tin and its alloys*. London: Edward Arnold.

Heilmeyer, W.-D., 2004. Ancient workshops and ancient 'art'. *Oxford Journal of Archaeology*, 23 (4), 403–415.

Helly, B., ed., 1994. *La Thessalie: Quinze Années de Recherches Archéologiques, 1975-1990. Bilans et Perspectives. Actes du Colloque International, Lyon, 17-22 Avril 1990, vol. A.* Athens: Ministry of Culture.

Helly, B., 1995. *L'état thessalien : Aleuas le Roux, les tétrades et les tagoi*. Lyon: Maison de l'Orient Méditerranéen.

Henderson, J. and Manti, P., 2008. Improving access to collections for sampling. *In*: D. Saunders, J.H. Townsend, and S. Woodcock, eds. *Conservation and Access. Contributions to the London Congress, 15-19 September 2008*. London: ICC, 115–119.

Hendon, J.A., 2000. Having and holding: storage, memory, knowledge, and social relations. *American Anthropologist*, 102 (1), 42–53.

Hiller, S., 1979. Ka-ko na wi-jo. Notes on interdependence of temple and bronze in the Aegean Bronze Age. *In*: E. Risch and H. Mühlestein, eds. *Colloquium Mycenaeum, The Sixth International Congress on the Aegean and Mycenaean Texts at Chaumont sur Neuchâtel, 7-13/9/1975*. Neuchâtel, 189–195.

Hodder, I., ed., 1982. *Symbolic and structural archaeology*. Cambridge: Cambridge University Press.

Hodder, I., 2011. Human-thing entanglement: towards an integrated archaeological perspective. *Journal of the Royal Anthropological Institute*, 17, 154–177.

Hodder, I., ed., 2012a. *Archaeological theory today*. 2nd ed. Malden, MA: Polity.

Hodder, I., 2012b. *Entangled: an archaeology of the relationships between humans and things*. Chichester: Wiley-Blackwell.

Hoffman, G., 1997. *Imports and Immigrants. Near Eastern Contacts with Iron Age Crete*. Michigan.

Hope Simpson, R. and Dickinson, O., 1979. *A gazetteer of Aegean civilisation in the Bronze Age Vol. I. The mainland and islands.* Göteborg: Paul Åströms Förlag.

Hopper, R.J., 1968. The Laurion Mines: A Reconsideration. *BSA*, 63, 293–326.

Hopper, R.J., 1979. *Trade and Industry in Classical Greece*. London: Thames and Hudson.

Hornblower, S., 1986. Greece: The History of the Classical Period. *In*: J. Boardman, J. Griffin, and O. Murray, eds. *The Oxford History of the Classical World*. Oxford, New York: Oxford University Press, 124–155.

Hourmouziadis, G., 1982. Ancient Magnesia. *In*: G. Hourmouziadis, P. Asimakopoulou-Atzaka, and K.A. Makris, eds. *Magnesia. The Story of a Civilization*. Athens: Capon, 9–103.

Hruby, Z.X. and Flad, R.K., eds., 2007. *Rethinking craft specialization in complex societies: archaeological analyses of the social meaning of production*. Berkeley, CA: American Anthropological Association.

Hruby, Z.X., Flad, R.K., Clark, J.E., Inomata, T., and Miller, H.M.-L., 2007. On 'rethinking' craft specialization: responses by the authors. *Archaeological Papers of the American Anthropological Association*, 17, 181–192.

Ingo, G.M., Angelini, E., De Caro, T., Bultrini, G., and Calliari, I., 2004. Combined use of GDOES, SEM+EDS, XRF and OM for the microchemical study of the corrosion products on archaeological bronzes. *Applied Physics A: Materials Science & Processing*, 79 (2), 199–203.

Ingo, G.M., Balbi, S., De Caro, T., Fragalà, I., Angelini, E., and Bultrini, G., 2006. Combined use of SEM-EDS, OM and XRF for the characterization of corrosion products grown on silver Roman coins. *Applied Physics A: Materials Science & Processing*, 83, 493–497.

Ingo, G.M., De Caro, T., Riccucci, C., Angelini, E., Grassini, S., Balbi, S., Bernardini, P., Salvi, D., Bousselmi, L., Çilingiroglu, A., Gener, M., Al Jarrah, O., Khosroff, S., Mahdjoub, Z., Al Saad, Z., El-Saddik, W., and Vassiliou, P., 2006. Large scale investigation of chemical composition, structure and corrosion mechanism of bronze archaeological artefacts from Mediterranean basin. *Applied Physics A: Materials Science & Processing*, 83 (4), 513–520.

Ingo, G.M., De Caro, T., Riccucci, C., and Khosroff, S., 2006. Uncommon Corrosion Phenomena of Archaeological Bronzes. *Applied Physics A: Materials Science & Processing*, 83 (4), 581–588.

Ingold, T., 2001. Beyond Art and Technology: The Anthropology of Skill. *In*: M.B. Schiffer, ed. *Anthropological Perspectives on Technology*. Albuquerque: University of New Mexico, 17–31.

Intzesiloglou, C.G., 2006. Η Ιτωνία Αθηνά και το Θεσσαλικό Ομοσπονδιακό Ιερό στη Φίλια Καρδίτσας. *In*: *Arxaiologiko Ergo Thessalias kai Stereas Elladas 1. Praktika Epistimonikis Synantisis, Volos 27.2-2.3.2003, vol. I: Thessalia*. Volos: YPPO, University of Thessaly, 221–237.

Jacobsthal, P., 1956. *Greek Pins*. Oxford: Clarendon Press.

Jenkins, D.A., 1989. Trace element geochemistry in archaeological sites. *Environmental Geochemistry and Health*, 11 (2), 57–62.

De Jesus, P.S., 1978. Considerations on the occurrence and exploitation of tin sources in the ancient Near East. *In*: A.D. Franklin, J.S. Olin, and T.A. Wertime, eds. *The Search for Ancient Tin*. Washingtong D.C.: Smithsonian Museum, 33–38.

Jobe, L.L., 1992. Finding the evidence. *Aramco World*, 43 (1), 18–19.

Johnston, I., tran., 2008. *Aristophanes: Clouds*. Virginia: Richer Resources Publications.

Jones, A., 2004. Archaeometry and Materiality: Materials-based Analysis in Theory and Practice. *Archaeometry*, 46 (3), 327–338.

Jones, A., 2007. *Memory and material culture*. Cambridge: Cambridge University Press.

Jones, R.E., 1980. Appendix D: Analysis of Bronze and other Base Metal Objects from the Cemeteries. *In*: M.R. Popham, L.H. Sackett, and P.G. Themelis, eds. *Lefkandi I: The Iron Age: the Settlement and the Cemeteries, vol. 1, Text*. London: BSA Suppl. vol. 11, 447–459.

Kakavogiannis, E., 1977. Ανασκαφικές έρευνες στις Φερές της Θεσσαλίας το 1977. *Archaeologica Analekta ex Athenon*, 10, 174–187.

Kalligas, P., 1992. Θεσσαλία και Εύβοια κατά την Πρώιμη Εποχή του Σιδήρου, 11ος-9ος αι. π.Χ. *In*: E. Kypraiou, ed. *Διεθνές Συνέδριο για την Αρχαία Θεσσαλία στη Μνήμη του Δημήτρη Ρ. Θεοχάρη (International Conference for Ancient Thessaly in the Memory of D.R. Theocharis)*. Athens: Ministry of Culture, 298–307.

Kamilakis, P. and Polymerou-Kamilaki, A., 1990. *Υπέρεια, Πρακτικά Α΄ Συνεδρίου ‘Φεραί-Βελεστίνο-Ρήγας’, Βελεστίνο 30/31 Μαΐου - 1 Ιουνίου 1986*. Athens: Scientific Society for the Research of Pherae-Velestino-Rigas.

Kamilli, R.J. and Criss, R.E., 1996. Genesis of the Silsilah tin deposit, Kingdom of Saudi Arabia. *Economic Geology*, 91, 1414–1434.

Kampouroglou, E.M., 1994. Η Γεωμορφολογική Εξέλιξη του Κόλπου του Βόλου από τη Νεολιθική Εποχή μέχρι Σήμερα. *In*: B. Helly, ed. *La Thessalie: Quinze Années de Recherches Archéologiques, 1975-1990. Bilans et Perspectives. Actes du Colloque International, Lyon, 17-22 Avril 1990, vol. A.* Athens: Scientific Society for the Research of Pherae-Velestino-Rigas, 41–52.

Kantarelou, V., Karydas, A.G., Zarkadas, C., Giannoulaki, M., and Argyropoulos, V., 2007. Micro-XRF Analysis of High Tin Bronze Mirrors at the Museum of Ancient Messene in Greece. *In*: V. Argyropoulos, A. Hein, and M. Abdel-Harith, eds. *Strategies for Saving our Cultural Heritage*. Athens: TEI of Athens, 93–99.

Kaplan, E., 1983. Türkiye madencilik tarihi içinde kalayın önemi ve kökeni. *MTA Enstitüsü Dergisi*, 95/96, 164–172.

Karageorghis, V. and Kassianidou, V., 1999. Metalworking and Recycling in Late Bronze Age Cyprus – The evidence from Kition. *Oxford Journal of Archaeology*, 18 (2), 171–188.

Karamberopoulos, D., ed., 2002. *Υπέρεια, Πρακτικά Γ΄ Διεθνούς Συνεδρίου Φεραί - Βελεστίνο - Ρήγας, Βελεστίνο, 2-5 Οκτωβρίου 1997*. Scientific Society for the Research of Pherae-Velestino-Rigas.

Karamberopoulos, D., ed., 2006. *Υπέρεια, Πρακτικά Δ΄ Διεθνούς Συνεδρίου (Φεραί-Βελεστίνο-Ρήγας), Βελεστίνο 2-5 Οκτωβρίου 2003*. Scientific Society for the Research of Pherae-Velestino-Rigas.

Karamberopoulos, D. and Kakavogiannis, E., eds., 1994. *Υπέρεια, Πρακτικά Β΄ Συνεδρίου ‘Φεραί-Βελεστίνο-Ρήγας’, Βελεστίνο 2-4 Οκτωβρίου 1992*. Athens: Stamoulis.

Karydas, A.G., 2007. Application of a Portable XRF Spectrometer for the Non-invasive Analysis of Museum Metal Artefacts. *Annali di Chimica*, 97, 419–432.

Karydas, A.G. and Asderaki-Tzoumerkioti, E., 2011. XRF analyses of four silver gilded Hellenistic epaulettes. *In*: I. Turbanti-Memmi, ed. *Proceedings of the 37th International Symposium on Archaeometry*. Berlin, Heidelberg: Springer-Verlag, 569–574.

Karydas, A.G., Kotzamani, D., Bernard, R., Barrandon, J.N., and Zarkadas, C., 2004. A compositional study of a museum jewellery collection (7th–1st c. BC) by means of a portable XRF spectrometer. *Nuclear Instruments and Methods in Physics Research B*, 226, 15–28.

Kassianidou, V., 2005. Was copper production under divine protection in Late Bronze Age Cyprus? Some thoughts on an old question. *In*: V. Karageorghis, H. Matthäus, and S. Rogge, eds. *Cyprus: Religion and Society from the Late Bronze Age to the end of the Archaic Period*. Möhnesee: Bibliopolis, 127–141.

Kassianidou, V. and Knapp, A.B., 2005. Archaeometallurgy in the Mediterranean: The Social Context of Mining, Technology and Trade. *In*: E. Blake and A.B. Knapp, eds. *The Archaeology of Mediterranean Prehistory*. Oxford: Blackwell, 215–251.

Kayafa, M., 2006. From Late Bronze Age to Early Iron Age Copper Metallurgy in Mainland Greece and Offshore Aegean Islands. *In*: S. Deger-Jalkotzy and I. Lemos, eds. *Ancient Greece: from the Mycenean palaces to the Age of Homer*. Edinburgh: Edinburgh University Press, 213–231.

Keane, W., 2008. The evidence of the senses and the materiality of religion. *Journal of the Royal Anthropological Institute*, 14 (S1, The objects of evidence: anthropological approaches to the production of knowledge), S110–S127.

Key, C.A., 1963. Notes on the trace element content of the artifacts of the Kfar Monash hoard. *Israel Exploration Journal*, 13, 289–290.

Kilian, K., 1975. *Fibeln in Thessalien von der mykenischen bis zur archaischen Zeit*. München: Beck.

Kilian, K., 1983. Weihungen aus Eisen und Eisenverarbeitung im Heiligtum zu Philia (Thessalien). *In*: R. Hägg, ed. *The Greek Renaissance of the Eighth Century BC: Tradition and Innovation*. Stockholm: Paul Åströms Förlag, 131–146.

Kilian-Dirlmeier, I., 1979. *Anhänger in Griechenland von der mykenischen bis zur spätgeometrischen Zeit*. München: Beck.

Kilian-Dirlmeier, I., 1985. Fremde Weihungen in griechischen Heiligtümern vom 8. bis zum Beginn des 7. Jahrhunderts v. Chr. *Jahrbuch des Römisch-germanischen Zentralmuseums, Mainz*, 32, 215–54.

Killick, D., 2002. Technology and social agency: outlining a practice theory for archaeology by Anne-Marcia Dobres (review). *American Anthropologist*, 104 (1), 348–349.

Killick, D., 2015. The awkward adolescence of archaeological science. *Journal of Archaeological Science*, 56 (Scoping the Future of Archaeological Science: Papers in Honour of Richard Klein), 242–247.

Klaproth, M.H., 1798. Mémoire de numismatique docimastique. *Mémoire de l'académie royale des sciences et belles-lettres, Berlin, Classe de philosophie expérimentale*, 97–113.

Kleinbrink, M., Kindberg Jacobsen, J., and Handberg, S., 2004. Water for Athena: Votive Gifts at Lagaria (Timpone della Motta, Francavilla Marittima, Calabria). *World Archaeology*, 36 (1), 43–67.

Knapp, A.B., 1986. *Copper Production and Divine Protection: Archaeology, Ideology and Social Complexity on Bronze Age Cyprus*. Göteborg: Paul Åströms Förlag.

Knapp, A.B. and van Dommelen, P., 2010. Material connections: mobility, materiality and Mediterranean identities. *In*: A.B. Knapp and P. van Dommelen, eds. *Material Connections in the Ancient Mediterranean: Mobility, Materiality and Identity*. London and NY: Routledge, 1–18.

Knappett, C., 2012. Materiality. *In*: I. Hodder, ed. *Archaeological theory today*. Malden, MA: Polity, 188–207.

Konophagos, K., 1980. *Le Laurium Antique*. Athens.

Kordellas, A., 1878. *Greece considered from a geological and mineralogical point of view*. Report submitted to the Comission for the Encouragement of Greek Industry.

Kordellas, A., 1902. *The mineral wealth and salt pans of Greece from a geological, statistical, and historical perspective*. Athens: Sakellariou.

Kostoglou, M., 2008. Toward an integrated approach to the study of ancient Greek technology. *In*: Y. Fakorelis, N. Zacharias, and K. Polikreti, eds. *Proceedings of the 4th International Symposium of the Hellenic Society for Archaeometry*. Oxford: Archaeopress, 456–68.

Kostoglou, M., 2010. Iron, Connectivity and Local Identities in the Iron Age Mediterranean. *In*: A.B. Knapp and P. van Dommelen, eds. *Material Connections in the Ancient Mediterranean: Mobility, Materiality and Identity*. London and NY: Routledge, 170–189.

Kostoglou, M., 2011. Iron, connectivity and local identities in the Iron Age to Classical Mediterranean. *In*: P. van Dommelen and A.B. Knapp, eds. *Material Connections in the Ancient Mediterranean: Mobility, Materiality and Identity*. London: Routledge, 170–189.

Kostoglou, M., 2013. Manufacturing techniques, technological traditions and social choices in ancient Greece. *In*: J. Humphris and T. Rehren, eds. *The World of Iron*. London: Archetype, 313–321.

Kraus, T., 1960. *Hekate. Studien zu Wesen und Bild der Göttin in Kleinasien und Griechenland*. Heidelberg: C. Winter.

Kroll, J.H., 2008. Early Iron Age Balance Weights at Lefkandi, Euboea. *Oxford Journal of Archaeology*, 27, 37–48.

Kuijt, I., 2001. Place, death, and the transmission of social memory in early agricultural communities of the Near Eastern pre-pottery Neolithic. *Archaeological Papers of the American Anthropological Association*, 10, 80–99.

Kuisma-Kursula, P., 2000. Accuracy, Precision and Detection Limits of SEM–WDS, SEM–EDS and PIXE in the Multi-Elemental Analysis of Medieval Glass. *X-Ray Spectrometry*, 29, 111–118.

Kuzmina, E.E., 1966. *Metallicheskie izdeliia eneolita i bronzovogo veka v srednei Azii*. Moscow: HayKa.

Kyparissi-Apostolika, N., Papakonstantinou, M., and Pantelidou-Gofa, M., eds., 2003. *The Mycenaean periphery: some theoritical and methodological considerations*. Athens: Ministry of Culture.

Langdon, S., 1987. Gift Exchange in the Geometric Sanctuaries. *In*: T. Linders and G.C. Nordquist, eds. *Gifts to the Gods, Proceedings of the Uppsala Symposium 1985*. Uppsala, 107–113.

Langdon, S., ed., 1997. *New Light on a Dark Age: Exploring the Culture of Geometric Greece*. Columbia and London: University of Missouri Press.

Langdon, S., 1999. Figurines and social change: visualising gender in Dark Age Greece. *In*: N.L. Wicker and B. Arnold, eds. *From the ground up: beyond gender theory in archaeology*. Oxford: Archaeopress, 23–30.

Laughlin, G.J. and Todd, J.A., 2000. Evidence for Early Bronze Age tin ore processing. *Materials Characterization*, 45 (4-5), 269–273.

Leake, W.M., 1835. *Travels in Northern Greece*. London: J. Bodwell.

Lechtman, H., 1996. Arsenic bronze: dirty copper or chosen alloy? A view from the Americas. *Journal of Field Archaeology*, 23, 477–514.

Lee, M.M., 2015. *Body, dress and identity in ancient Greece*. Cambridge: Cambridge University Press.

Van der Leeuw, S.E. and Torrence, R., 1989. *What's new? a closer look at the process of innovation*. London: Unwin Hyman.

Legnaioli, S., Cristoforetti, G., Palleschi, V., Salvetti, A., and Tognoni, E., 2007. In situ LIBS and XRF analysis of the Porticello bronze statues at National Museum of Magna Grecia in Reggio Calabria. *In*: V. Argyropoulos, A. Hein, and M. Abdel-Harith, eds. *Strategies for Saving our Cultural Heritage*. Athens: TEI of Athens, 100–104.

Lehner, J.W. and Yener, K.A., 2014. Organization and specialization of early mining and metal technologies in Anatolia. *In*: B.W. Roberts and C.P. Thornton, eds. *Archaeometallurgy in Global Perpective: Methods and Syntheses*. New York: Springer, 529–557.

Lemonnier, P., ed., 1993. *Technological Choices: Transformation in material Cultures since the Neolithic*. London and NY: Routledge.

Lemonnier, P., 2012. *Mundane objects: materiality and non-verbal communication*. Walnut Creek, CA: Left Coast Press.

Lemos, I., 1996. A Euboean Potter/ Painter from Lefkandi. *In*: D. Evely, I. Lemos, and S. Sherratt, eds. *Minotaur and Centaur, Studies in the Archaeology of Crete and Euboea presented to Mervyn Popham*. Oxford: Archaeopress, 122–125.

Lemos, I., 2000. Songs for Heroes: the lack of images in early Greece. *In*: K.N. Rutter and A. Sparkes, eds. *Word and Image in Ancient Greece*. Edinburgh: Edinburgh University Press, 11–21.

Lemos, I., 2001. The Lefkandi Connection: networking in the Aegean and the Eastern Mediterranean. *In*: L. Bonfante and V. Karageorghis, eds. *Italy and Cyprus in Antiquity: 1500-450 BC. Proceedings of an International Symposium held at the Italian Academy for Advanced Studies in America at Columbia University, November 16-18 2000*. Nicosia: Severis Foundation, 215–226.

Lemos, I., 2002. *The Protogeometric Aegean: the archaeology of the late 11th and 10th c. BC*. Oxford: Oxford University Press.

Lemos, I., 2003. Craftsmen, traders and some wives in Early Iron Age Greece. *In*: N.C. Stampolidis and V. Karageorghis, eds. *ΠΛΟΕΣ, Sea Routes: Interconnections in the Mediterranean 16th – 6th c. BC. Proceedings of the International Symposium held at Rethymnon, Crete*. Athens, 187–195.

Van Leuven, J.C., 1981. Problems and Methods of Prehellenic Naology. *In*: N. Marinatos and R. Hägg, eds. *Sanctuaries and Cults in the Aegean Bronze Age: proceedings of the first international symposium at the Swedish Institute in Athens, 12-13 May, 1980*. Stockholm: Svenska institutet i Athen, 11–25.

Lewin, S.Z., 1972. A new approach to establishing the authenticity of patinas on copper-base artifacts. *In*: W.J. Young, ed. *Application of science in examination of works of art*. Boston, Massachusetts: Museum of Fine Arts, 36–41.

Linders, T., 1987. Gods, Gifts, Society. *In*: T. Linders and G.C. Nordquist, eds. *Gifts to the Gods, Proceedings of the Uppsala Symposium 1985*. Uppsala, 115–122.

Linders, T., 1992. Sacred Finances: Some Observations. *In*: T. Linders and B. Alroth, eds. *Economics of Cult in the Ancient Greek World, Proceedings of the Uppsala Symposium 1990*. Uppsala, 9–13.

Linders, T. and Alroth, B., eds., 1992. *Economics of Cult in the Ancient Greek World, Proceedings of the Uppsala Symposium 1990*. Uppsala.

Linders, T. and Nordquist, G.C., eds., 1987. *Gifts to the Gods, Proceedings of the Uppsala Symposium 1985*. Uppsala.

Lutz, J. and Pernicka, E., 1996. Energy Dispersive X-Ray Fluorescence Analysis of Ancient Copper Alloys: Empirical Values for Precision and Accuracy. *Archaeometry*, 38 (2), 313–323.

Lyttkens, C.H., 1997. A rational-actor perspective on the origin of the liturgies in ancient Greece. *Journal of Institutional and Theoritical Economics*, 153 (3), 462–484.

Lyttkens, C.H., 2010. Institutions, taxation, and market relationships in ancient Athens. *Journal of Institutional Economics*, 6, 505–527.

Lyttkens, C.H., 2013. *Economic analysis of institutional change in ancient Greece: politics, taxation and rational behaviour*. London: Rou.

Malkin, I., 2011. *A small Greek world: networks in the Ancient Mediterranean*. Oxford; New York: Oxford University Press.

Mangou, H. and Ioannou, P.V., 1997. On the Chemical Composition of Prehistoric Greek Copper-Based Artefacts from the Aegean Region. *BSA*, 92, 59–72.

Mangou, H. and Ioannou, P.V., 1998. On the Chemical Composition of Prehistoric Greek Copper-Based Artefacts from Crete. *BSA*, 93, 91–102.

Mangou, H. and Ioannou, P.V., 1999. On the Chemical Composition of Prehistoric Greek Copper-Based Artefacts from Mainland Greece. *BSA*, 94, 81–100.

Mangou, H., Pernot, M., and Rolley, C., 1991. Bronzes orientaux et orientalisants : Analyses complémentaires. *BCH*, 115 (2), 561–577.

Mangou, H., Philippakis, S., and Rolley, C., 1986. Trépieds géométriques de bronze, Analyses complémentaires. *BCH*, 110 (1), 121–1236.

Marakas, G., 2010. *Ritual practice between the Late Bronze Age and Protogeometric periods of Greece*. Oxford: Archaeopress.

Margaris, N., Galogiannis, C., and Grammatikaki, M., 2006. Water management in Thessaly, Central Greece. *Groundwater and Ecosystems*, 70, 237–242.

Marinatos, N., 1993. What are Greek Sanctuaries? A Synthesis. *In*: N. Marina and R. Hägg, eds. *Greek Sanctuaries: New Approaches*. London and NY: Routledge, 228–233.

Marinos, G.P. and Petrascheck, W.F., 1956. *Lavrion, Geological and Geophysical Research*. Athens: IGME.

Martin, S.R., 1999. *Wonderful Power: The story of ancient copper working in the Lake Superior Basin*. Detroit, Michigan: Wayne State University Press.

Martinón-Torres, M., 2002. Chaîne Opératoire: The concept and its aplications within the study of technology. *Gallaecia*, 21, 29–44.

Martinón-Torres, M. and Killick, D., 2015. Archaeological Theories and Archaeological Sciences. *In*: A. Gardner, M. Lake, and U. Sommer, eds. *The Oxford Handbook of Archaeological Theory*. Oxford: Oxford University Press.

Martinón-Torres, M., Li, X.J., Bevan, A., Xia, Y., Zhao, K., and Rehren, T., 2012. Forty thousand arms for a single emperor: from chemical data to the labor organization behind the bronze arrows of the Terracotta Army. *Journal of Archaeological Method and Theory*, 19, 1–29.

Masson, V. and Sariandie, V., 1972. *Central Asia*. London: Thames and Hudson.

Mauss, M., 2002. *The Gift: the Form and Reason for Exchange in Archaic Societies, with a forward by M. Douglas*. London and NY: Routledge.

Mazarakis Ainian, A., 1988. Early Greek temples: their origin and function. *In*: R. Hägg, N. Marinatos, and G.C. Nordquist, eds. *Early Greek Cult Practice, Proceedings of the 5th International Symposium at the Swedish Institute at Athens, 26-29 June, 1986*. Stockholm: Paul Åströms Förlag, 105–119.

Mazarakis Ainian, A., 1997. *From ruler's dwellings to temples: architecture, religion and society in Early Iron Age Greece (1100-700 BC)*. Jonsered: Paul Åströms Förlag.

McDonald, W.A., Coulson, W.D.E., and Rosser, J., eds., 1983. *Excavations at Nichoria in Southwest Greece. Volume III: Dark Age and Byzantine Occupation*. Minneapolis, Minnesota: University of Minnesota Press.

McDonald, W.A., Shay, C.T., Wilkie, N., Simpson, R.H., Coulson, W.D.E., Donovan, W.P., Blitzer, H., Rosser, J., Aschenbrenner, S., Howell, R.J., Dickinson, O., Hughes-Brock, H., Wade, W.D., Wolberg, D.L., Grady, F.V., Sloan, R.E., Shay, J., Rapp, G., and Cooke, S.R.B., 1975. Excavations at Nichoria in Messenia: 1972-1973. *THe Journal of the American School of Classical Studies at Athens*, 44 (1), 69–141.

McGeehan-Liritzis, V. and Gale, N.H., 1988. Chemical and lead isotope analyses of Greek Late Neolithic and Early Bronze Age metals. *Archaeometry*, 30, 199–225.

McGeehan-Liritzis, V. and Taylor, J.W., 1987. Yugoslavian tin deposits and the Early Bronze Age industries of the Aegean region. *Oxford Journal of Archaeology*, 6 (3), 287–300.

McKerrell, H., 1978. The use of tin-bronze in Britain and the comparative relationship with the Near East. *In*: A.D. Franklin, J.S. Olin, and T.A. Wertime, eds. *The Search for Ancient Tin*. Washingtong D.C.: Smithsonian Museum, 7–24.

McKerrell, H. and Tylecote, R.F., 1972. The working of copper-arsenic alloys in Early Bronze Age and the effect on the determination of provenance. *Procedings of the Prehistoric Society*, 38, 209–218.

McNeil, M. and Selwyn, L.S., 2001. Electrochemical Processes in Metallic Corrosion. *In*: D.R. Brothwell and A.M. Pollard, eds. *Handbook of Archaeological Sciences*. Chichester, New York: John Wiley & Sons, 605–614.

Meeks, N.D., 1986. Tin-rich Surfaces on Bronze - Some Experimental and Archaeological Considerations. *Archaeometry*, 28 (2), 133–162.

Meeks, N.D., 1993a. Patination phenomena on Roman and Chinese high-tin bronze mirrors and other artefacts. *In*: S. La Niece and P.T. Craddock, eds. *Metal Plating and Patination*. Oxford: Butterworth-Heinemann, 63–84.

Meeks, N.D., 1993b. Surface Characterization of Tinned Bronzes, High Tin Bronze, Tinned Iron and Arsenical Bronze. *In*: S. La Niece and P.T. Craddock, eds. *Metal Plating and Patination*. Oxford: Butterworth-Heinemann, 247–275.

Meirion Jones, A. and Bradley, R., eds., 2012. *Image, memory and monumentality: archaeological engagements with the material world: a celebration of the academic achievements of Professor Richard Bradley*. Oxford: Oxbow Books.

Mili, M., 2014. *Religion and society in ancient Thessaly*. Oxford: Oxford University Press.

Miller, D., ed., 2005. *Materiality*. Durham: Duke University Press.

Miller, D., 2010. *Stuff*. Cambridge: Polity.

Miller, S.G., 1974. The Altar of the Six Goddesses in Thessalian Pherai. *California Studies in Classical Antiquity*, 7, 231–256.

Mitropoulou, E., 1990. Λατρείες Φερών, ανάγλυφο Κυβέλης και ανάγλυφο χεριού. *In*: P. Kamilakis and A. Polymerou-Kamilaki, eds. *Hypereia 1*. 70–81.

Mitropoulou, E., 1992. Αγαλματίδια Αρτέμιδος στο Μουσείο του Βόλου. *In*: E. Kypraiou, ed. *Διεθνές Συνέδριο για την Αρχαία Θεσσαλία στη Μνήμη του Δημήμτρη Ρ. Θεοχάρη (International Conference for Ancient Thessaly in the Memory of D.R. Theocharis)*. Athens: Ministry of Culture, 326–332.

Moletsane, R., Mitchell, C., and Smith, A., eds., 2012. *Was it something I wore? Dress, identity, materiality*. Cape Town: Human Sciences Research Council Press.

Morgan, C., 1993. The origins of Pan-Hellenism. *In*: N. Marinatos and R. Hägg, eds. *Greek Sanctuaries: New Approaches*. London and NY: Routledge, 18–44.

Morgan, C., 1996. From Palace to Polis? Religious Developments on the Greek Mainland during the Bronze Age/ Iron Age Transition. *In*: P. Hellström and B. Alroth, eds. *Religion and Power in the Ancient Greek World*. Uppsala, 41–57.

Morgan, C., 2000. Politics without the Polis: Cities and the Achaean Ethnos, c. 800-500 BC. *In*: R. Brock and S. Hodkinson, eds. *Alternatives to Athens: Varieties of Political Organization and Community in Ancient Greece*. Oxford, New York: Oxford University Press, 189–211.

Morgan, C., 2003. *Early Greek States Beyond the Polis*. London and NY: Routledge.

Morgan, C., 2006. Ethne in the Peloponnese and Central Greece. *In*: S. Deger-Jalkotzy and I. Lemos, eds. *Ancient Greece: from the Mycenean palaces to the Age of Homer*. Edinburgh: Edinburgh University Press, 233–254.

Morris, I., 1986. Gift and Commodity in Archaic Greece. *Man*, 21, 1–17.

Morris, I., 1989. Circulation, Deposition and the Formation of the Greek Iron Age. *Man*, 26, 502–19.

Morris, I., 2000. *Archaeology as Cultural History: Words and Things in Iron Age Greece.* Malden: Blackwell.

Morris, I., 2005. Archaeology, standards of living, and Greek economic history. *In*: J.G. Manning and I. Morris, eds. *The ancient economy: evidence and models*. Stanford, California: Stanford University Press, 91–126.

Muhly, J., 1976. *Copper and Tin*. New Haven; Connecticut: Academy of Arts and Sciences.

Muhly, J.D., 1973a. Tin trade routes of the Bronze Age: New evidence and new techniques aid in the study ofmetal sources of the ancient world. *American Scientist*, 61 (4), 404–413.

Muhly, J.D., 1973b. Copper and tin: he distribution of mineral resources and the nature of the metals trade n the Bronze Age. *Transactions of the Connecticut Academy of Arts and Sciences*, 43, 155–535.

Muhly, J.D., 1985. Sources of tin and the beginnings of bronze metallurgy. *American Journal of Archaeology*, 89, 275–291.

Muhly, J.D., 1993. Early Bronze Age Tin and the Taurus. *American Journal of Archaeology*, 97 (2), 239–253.

Muhly, J.D., 1998. Copper, tin, silver and iron: the search for metallic ores as an incentive for foreign expansion. *In*: S. Gitin, A. Mazan, and E. Stern, eds. *Mediterranean peoples in transition. Thirteenth to early tenth centuries BCE: in honor of professor Trude Dothan*. Jerusalem: Israel Exploration Society, 314–352.

Muhly, J.D., 1999. Copper and bronze in Cyprus and the Eastern Mediterranean. *In*: V.C. Pigott, ed. *The Archaeometallurgy of the Asian Old World*. USA: University of Pennsylvania Museum, 15–25.

Muhly, J.D., 2005. Traveling craftsmen: Love ’em or leave ’em. *In*: R. Laffineur and E. Greco, eds. *Emporia: Aegean in the Central and Eastern Mediterranean. Proceedings of the 10th International Conference, Italian School of Archaeology, Athens, 14-18 April 2004*. Liège: Université de Liège, 685–690.

Muhly, J.D., 2008. An introduction to Minoan archaeometallurgy. *In*: I. Tzachili, ed. *Aegean Metallurgy in the Bronze Age. Proceedings of the International Symposium held at the University of Crete, Rhethymnon, Greece, on November 19-21, 2004*. Athens: Ta Pragmata Publications, 35–41.

Muscarella, O.W., 1967. *Phrygian Fibulae from Gordion*. London: Colt Archaeological Institute.

Mylonas, G., 1959. *Agios Kosmas: an Early Bronze Age settlement and cemetery in Attica*. Princeton, NJ: Princeton University Press.

Needham, S.P., Leese, M.N., Hook, D.R., and Hughes, M.J., 1989. Developments in the Early Bronze Age metallurgy of southen Britain. *World Archaeology*, 20 (3), 383–402.

Niemeier, W.-D., 2013. *The oracle sanctuary of Apollon at Abai/Kalapodi: Cult continuity from the Mycenaean to the Roman Imperial period in one of the most important sanctuaries of ancient Greece*. Lecture Presented at The Institute of Fine Arts, 22.03.2013. New York.

Northover, J.P., 1989a. The copper and tin ingots from the Kaş Shipwreck. *In*: A. Hauptmann, E. Pernicka, and G.A. Wagner, eds. *Old World Archaeometallurgy*. Bochum: Deutsches Bergbau-Museum, 99–105.

Northover, J.P., 1989b. Properties and use of arsenic-copper alloys. *In*: A. Hauptmann, E. Pernicka, and G.A. Wagner, eds. *Old World Archaeometallurgy*. Bochum: Deutsches Bergbau-Museum, 111–118.

Northover, J.P. and Gillis, C., 1999. Questions on the analysis of ancient tin. *In*: S.M.M. Young, A.M. Pollard, P. Budd, and R.A. Ixer, eds. *Metals in Antiquity*. Oxford: Archaeopress, 78–85.

Oddy, W.A. and Bimson, M., 1985. Tinned bronze in antiquity. *United Kingdom Institute of Conservation, Occasional Paper*, 3, 33–39.

Oddy, W.A. and Meeks, N.D., 1982. Unusual Corrosion Phenomena on Ancient Bronzes. *In*: N.S. Brommelle and G. Thomson, eds. *Science and Archaeology in the Service of Conservation. Preprints of the Contributions to the Washington Congress, 3-9 September 1982*. London: International Institute for Conservation of Historic and Artistic Works, 119–124.

Olick, J.K. and Robbins, J., 1998. Social memory studies: from ‘collective memory’ to the historical sociology of mnemonic practices. *Annual Review of Sociology*, 24, 105–140.

Orfanou, V., 2009. Bronze grave offerings from Early Iron Age Greece: a case study from the Toumba cemetery at Lefkandi, Euboea. MSc thesis. Institute of Archaeology, UCL, London.

Orfanou, V. and Rehren, T., forthcoming. Bronze grave offerings from the Toumba cemetery.

Orfanou, V. and Rehren, T., 2014. A (not so) dangerous method: pXRF vs. EPMA-WDS analyses of copper-based artefacts. *Journal of Archaeological and Anthropological Science*, [online].

Orlandini, P., 1965. Gela - Depositi votivi di bronzo premonetale nel santuario di Demetra Thesmophoros a Bitalemi. *AnnIstItNum*, 12-14, 1–20.

Osborne, R., 1998. *Archaic and Classical Greek Art*. Oxford: Oxford University Press.

Osborne, R., 2004. Hoards, Votives, Offerings: the Archaeology of the Dedicated Object. *World Archaeology*, 36, 1–10.

Osborne, R., 2009. *Greece in the Making (1200-479 BC)*. 2nd ed. London and NY: Routledge.

Østby, E., 1992. Der Dorische Tempel von Pherai. *Opuscula Atheniensia*, 19, 85–113.

Østby, E., 1994. A Reconsideration of the Classical Temple at Pherai. *In*: B. Helly, ed. *La Thessalie: Quinze Années de Recherches Archéologiques, 1975-1990. Bilans et Perspectives. Actes du Colloque International, Lyon, 17-22 Avril 1990, vol. B.* Athens: Ministry of Culture, 139–142.

Ottaway, B., 1994. *Prähistorische Archäometallurgie*. Espelkamp: Leidorf.

Ottaway, B.S., 2001. Innovation, production and specialization in early Prehistoric copper metallurgy. *European Journal of Archaeology*, 4 (1), 87–112.

Panagiotopoulos, D., 2012. Encountering the foreign. (De-)constructing alterity in the archaeologies of the Bronze Age Mediterranean. *In*: J. Maran and P.W. Stockhammer, eds. *Materiality and Social Practice: transformative capacities of intercultural encounters*. Oxford: Oxbow Books, 51–60.

Pantos, A., 1981. Εννοδία Οσία Θεσσαλική Θεά στην Βέροια. *Αρχαιογνωσία*, 2, 96–100.

Panvini, R., 2008. Is sistema delle offerte nei santuari chonii dell' acropoli di Gela. *In*: G. Greco and B. Ferrara, eds. *Doni agli Dei: il sistema dei doni votivi nei santuari. Atti del seminario di studi, Napoli 21 aprile 2006*. Napoli: Naus, 241–255.

Papadimitriou, G.D., 1991. Copper and Bronze Metallurgy in Ancient Greece. *In*: E. Pernicka and G.A. Wagner, eds. *Archaeometry '90. International Symposium on Archaeometry, 2-6 April 1990, Heidelberg, Germany*. Basel, Boston, Berlin: Birkhäuser, 117–126.

Papadimitriou, G.D., 1992. Μια προσπάθεια ιστορικής σύνδεσης των δεδομένων της αρχαιομεταλλουργίας με τιν εξέλιξη της παραγωγής χαλκού και μπρούτζου στην ελληνική αρχαιότητα. *In*: *Α' Συμπόσιο Αρχαιομετρίας: Σύνδεση Αρχαιομετρίας και Αρχαιολογίας, 26-28 Ιανουαρίου 1990, Αθήνα, Κέντρο Μελετών Ακροπόλεως*. Athens: Hellenic Society of Archaeometry, 113–122.

Papadimitriou, G.D., 2001. Η εξέλιξη των κραμάτων χαλκού στον ελλαδικό χώρο μέχρι το τέλος της γεωμετρικής εποχής: κραματικές προσμίξεις και τεχνολογική εξέλιξη. *In*: Y. Bassiakos, E. Aloupi, and Y. Facorellis, eds. *Archaeometry Issues in Greek Prehistory and Antiquity*. Athens: Hellenic Society of Archaeometry, Society of Messenian Archaeological Studies, 587–608.

Papadimitriou, G.D., 2008. The technological evolution of copper alloys in the Aegean during the Prehistoric period. *In*: I. Tzachili, ed. *Aegean Metallurgy in the Bronze Age. Proceedings of the International Symposium held at the University of Crete, Rhethymnon, Greece, on November 19-21, 2004*. Athens: Ta Pragmata Publications, 271–287.

Papadimitriou, G.D. and Fragiskos, A.Z., 2008. The study of ancient copper slag from Serifos. *In*: Y. Fakorelis, N. Zacharias, and K. Polikreti, eds. *Proceedings of the 4th International Symposium of the Hellenic Society for Archaeometry*. Oxford: Archaeopress, 529–534.

Papadimitriou, G.D., Vardavoulias, M., and Marini, R., 1992. Metallurgical Study of Ancient Slags Coming from Copper Production in Pelasghia-Larisa Kremaste in Greece. *In*: E. Antonacci Sanpaolo, ed. *Archaeometallurgia: Ricerche e Prospettive. Proceedings of International Colloqium on Archaeometallurgy*. Bologna: CLUEB, 207–226.

Papadopoulos, T.I. and Kontorli-Papadopoulou, L., 2006. Το Πρόβλημα των Τοπικών Ιδιορρυθμιών και Επείσακτων Στοιχείων στην Κεντρική Στερεά Ελλάδα (Φωκίδα, Βοιωτία, Φθιώτιδα) και τη Θεσσαλία κατά την Ύστερη Εποχή του Χαλκού. *In*: *Arxaiologiko Ergo Thessalias kai Stereas Elladas 1. Praktika Epistimonikis Synantisis, Volos 27.2-2.3.2003, vol. II: Sterea Ellada*. Volos: YPPO, University of Thessaly, 705–719.

Papadopoulou, A., 1994. Η Πολιτική Ανάπτυξη των Φερών κατά την Αρχαία Ιστορική Περίοδο. *In*: D. Karamberopoulos and E. Kakavogiannis, eds. *Hypereia 2, vol. 1*. 105–111.

Papageorgiou, S., Steiros, S., and Chourmouziadis, G., 1994. Σχέσεις Φυσικού Περιβάλλοντος/ Γεωμορφολικών Μεταβολών και Ιστορίας της Κατοίκησης στην Αρχαία Θεσσαλία. *In*: B. Helly, ed. *La Thessalie: Quinze Années de Recherches Archéologiques, 1975-1990. Bilans et Perspectives. Actes du Colloque International, Lyon, 17-22 Avril 1990, vol. A.* Athens: Ministry of Culture, 21–28.

Papastamataki, A., 1994. Copper slags and copper metallurgy in antiquity. *In*: *Bulletin de la Société Spéléologique de Grèce, XXI, 1993-1994, 5th Int. Congress, Athènes-Crète, 7-11/11/1994, 'Cave Development, Evolution and Environment'*. 371–376.

Papastamataki, A., Demetriou, D., and Orphanos, B., 1994. Mining and Metallurgical Activities in Pelasgia. The Production of Copper in Antiquity. *In*: B. Helly, ed. *La Thessalie: Quinze Années de Recherches Archéologiques, 1975-1990. Bilans et Perspectives. Actes du Colloque International, Lyon, 17-22 Avril 1990, vol. A.* Athens: Ministry of Culture, 243–248.

Papastamataki, A. and Dimitriou, D., 1987. Η Παραγωγή Χαλκού στην Πελασγία κατά την Αρχαιότητα. *Praktika Akademias Athenon*, 62 (1), 564–595.

Papastamataki, A., Dimitriou, D., and Orphanos, V., 1992. Ο Χαλκός της Πελασγίας και οι Πηγές του Χαλκούχου Μεταλλεύματος κατά την Αρχαιότητα. *In*: *Α' Συμπόσιο Αρχαιομετρίας: Σύνδεση Αρχαιομετρίας και Αρχαιολογίας, 26-28 Ιανουαρίου 1990, Αθήνα, Κέντρο Μελετών Ακροπόλεως*. Athens: Hellenic Society of Archaeometry, 95–109.

Parker, R., 1998. Pleasing Thighs: Reciprocity in Greek Religion. *In*: C. Gill, N. Postlethwaite, and R. Seaford, eds. *Reciprocity in Ancient Greece*. Oxford: Oxford University Press, 105–125.

Patterson, C.C., 1971. Native Copper, Silver, and Gold Accessible to Early Metallurgists. *American Antiquity*, 36 (3), 286–321.

Penhallurick, R.D., 1986. *Tin in Antiquity*. London: The Institute of Metals.

Pennebaker, J.W., Paez, D., and Rimé, B., eds., 1997. *Collective memory of political events: social psychological perspectives*. Mahwah, New Jersey: Lawrence Erlbaum Associates.

Pernicka, E., 1999. Trace Element Fingerprinting of Ancient Copper: A Guide to Technology or Provenance? *In*: S.M.M. Young, A.M. Pollard, P. Budd, and R.A. Ixer, eds. *Metals in Antiquity*. Oxford: Archaeopress, 163–171.

Pernicka, E., 2014a. Provenance determination of archaeological metal objects. *In*: B.W. Roberts and C.P. Thornton, eds. *Archaeometallurgy in Global Perpective: Methods and Syntheses*. New York: Springer, 239–268.

Pernicka, E., 2014b. *Isotopes in Archaeometallurgy*.

Pernicka, E., Begemann, F., Schmitt-Strecker, S., and Grimanis, A.P., 1990. On the composition of metal artefacts from Poliochni on Lemnos. *Oxford Journal of Archaeology*, 9, 263–297.

Pernicka, E., Wagner, G.A., Muhly, J.D., and Öztunali, Ö., 1992. Comment on the discussion of ancient tin sources in Anatolia. *Journal of Mediterranean Archaeology*, 5, 91–98.

Philipp, H., 1981. *Bronzeschmuck aus Olympia; mit einem Anhang von Imma Kilian-Dirlmeier*. Berlin: de Gruyter.

Phillips, J.A. and Louis, H., 1896. *A treatise on ore deposits*. London: Macmillan.

Phillips, O., 2002. The Witches' Thessaly. *In*: P. Mirecki and M. Meyer, eds. *Magic and Ritual in the Ancient World*. Leiden: Brill, 378–386.

Pickles, S., 1988. *Metallurgical changes in the Late Bronze Age Cyprus*. University of Edinburgh.

Plantzos, D., 2011. 'Il n'y a pas de hors-texte': το Μουσείο της Ακρόπολης και τα Απόνερα του Ιδεαλισμού. *Τετράδια Μουσειολογίας*, 7, 23–29.

De Polignac, F., 1984. *La naissance de la cité grecque : cultes, espace et société VIIIe-VIIe siècles*. Paris: Editions de la Découverte.

De Polignac, F., 1994. Mediation, Competition, and Sovereignty: the Evolution of Rural Sanctuaries in Geometric Greece. *In*: R. Osborne and S.E. Alcock, eds., R. Osborne, tran. *Placing the Gods: Sanctuaries and Sacred Space in Ancient Greece*. Oxford: Clarendon Press, 3–18.

Pollard, A.M., Batt, C., Stern, B., and Young, S.M.M., 2007. *Analytical Chemistry in Archaeology*. Cambridge: Cambridge University Press.

Pollard, A.M. and Bray, P.J., 2005. A Bicycle made for two? The integration of scientific techniques into archaeological interpretation. *Annual Review of Anthropology*, 36, 245–59.

Pollard, A.M. and Heron, C., 2008. *Archaeological Chemistry*. 2nd ed. Cambridge: Royal Society of Chemistry.

Popham, M.R., 1995. An Engraved Near Eastern Bronze Bowl from Lefkandi. *Oxford Journal of Archaeology*, 14 (1), 103–107.

Popham, M.R. and Lemos, I., 1995. A Euboean warrior trader. *Oxford Journal of Archaeology*, 14 (2), 151–157.

Popham, M.R. and Sackett, L.H., 1980. Historical conclusions. *In*: M.R. Popham, L.H. Sackett, and P.G. Themelis, eds. *Lefkandi I: The Iron Age: the Settlement and the Cemeteries*. BSA Suppl. vol. 11, 355–369.

Popham, M.R., Sackett, L.H., and Themelis, P.G., eds., 1980. *Lefkandi I: The Iron Age: the Settlement and the Cemeteries, vol. 1, Text*.

Proskynitopoulou, R., 2009. *National Archaeological Museum: the bronze collection*. Athens: Archaeological Receipts Fund.

Psaroudakis, K., 2003. Ιερά και Μεταλλοτεχνία στην Ανατολική Μεσόγειο από την Εποχή του Χαλκού στα Ιστορικά Χρόνια. *In*: N. Kyparissi-Apostolika and M. Papakonstantinou, eds. *The Periphery of the Mycenaean World, Proceedings of the 2nd International Interdisciplinary Colloquium, Lamia 1999*. Athens: Ministry of Culture, 581–585.

Pulak, C., 1998. The Uluburun shipwreck: and overview. *International Journal of Nautical Archaeology*, 27 (3), 188–224.

Pulak, C., 2000. The Copper and Tin Ingots from the Late Bronze Age Shipwreck at Uluburun. *Der Anschnitt*, 13, 137–157.

Pulak, C., 2001. The Cargo of the Uluburun Ship and Evidence for Trade with the Aegean and Beyond. *In*: L. Bonfante and V. Karageorghis, eds. *Italy and Cyprus in Antiquity: 1500-450 BC. Proceedings of an International Symposium held at the Italian Academy for Advanced Studies in America at Columbia University, November 16-18 2000*. Nicosia: Severis Foundation, 13–61.

Radivojević, M., Rehren, T., Kuzmanović-Cvetković, J., and Jovanović, M., 2014. Why are there tin bronzes in the 5th millennium Balkans? *In*: *Archaeotechnology: studying technology from Prehistory to the Middle Ages*. Belgrade: Srpsko arheološko društvo, 235–256.

Radivojević, M., Rehren, T., Kyzmanović-Cvetković, J., Jovanović, M., and Northover, J.P., 2013. Tainted ores and the rise of tin bronzes in Eurasia, c. 6500 years ago. *Antiquity*, 87, 1030–1045.

Rakatsanis, K. and Tziafalias, A., 1997. *Λατρείες και Ιερά στην Αρχαία Θεσσαλία. Α’ Πελασγιώτις*. Ioannina: University of Ioannina.

Rapp, G., Jones, R.E., and Henrickson, E., 1978. Analyses of the Metal Artifacts. *In*: G. Rapp and S. Aschenbrenner, eds. *Excavations at Nichoria in Southwest Greece, vol. 1, Site, Environs and Techniques*. Minneapolis, Minnesota: University of Minnesota Press, 166–181.

Rapp, G., Rothe, R., and Jing, Z., 1999. Using Neutron Activation Analysis to source ancient tin (cassiterite). *In*: S.M.M. Young, A.M. Pollard, P. Budd, and R.A. Ixer, eds. *Metals in Antiquity*. Oxford: Archaeopress, 153–162.

Raubitschek, I.K., 1998. *Isthmia VII: the Metal Objects (1952-1989)*. Princeton, NJ: The American School of Classical Studies at Athens.

Von Reden, S., 1998. The Commodification of Symbols: Reciprocity and its Perversions in Menander. *In*: C. Gill, N. Postlethwaite, and R. Seaford, eds. *Reciprocity in Ancient Greece*. Oxford: Oxford University Press, 255–278.

Rehren, T., 1996. A Roman zinc tablet from Bern, Switzerland: reconstruction of the manufacture. *In*: Ş. Demirci, A.M. Özer, and G.D. Summers, eds. *Archaeometry 94*. Tübitak, Ankara, 35–45.

Rehren, T., 1999. Small Size, Large Scale Roman Brass Production in Germania Inferior. *Journal of Archaeological Science*, 26, 1083–1087.

Rehren, T., Boscher, L., and Pernicka, E., 2012. Large scale smelting of speiss and arsenical copper at Early Bronze Age Arisman, Iran. *Journal of Archaeological Science*, 39, 1717–1727.

Rehren, T. and Martinón-Torres, M., 2008. Naturam ars imitata: European brassmaking between craft and science. *In*: M. Martinón-Torres and T. Rehren, eds. *Archaeology, history and science: integrating approaches to ancient materials*. Walnut Creek, CA: Left Coast Press, 167–188.

Renfrew, C., 1967. Cycladic metallurgy and the Aegean Early Bronze Age. *American Journal of Archaeology*, 71, 1–20.

Renfrew, C., 1973. Εμπόριο και τεχνική εκπαίδευση. *In*: D.R. Theocharis, ed. *Νεολιθική Ελλάς*. Athens, 191–192.

Renfrew, C., 1998a. Word of Minos: the Minoan contribution to Mycenaean Greek and the linguistic geography of the Bronze Age Aegean. *Cambridge Archaeological Journal*, 8, 239–264.

Renfrew, C., 1998b. Mind and matter: cognitive archaeology and external symbolic storage. *In*: C. Renfrew and C. Scarre, eds. *Cognition and Material Culture: the Archaeology of Symbolic Storage*. Cambridge: McDonald Archaeological Institute, 1–6.

Renfrew, C. and Scarre, C., eds., 1998. *Cognition and Material Culture: the Archaeology of Symbolic Storage*. Cambridge: McDonald Archaeological Institute.

Richter, G.M.A., 1988. *Kouroi: Archaic Greek youths - a study of the development of the Kouros type in Greek sculpture*. 3rd ed. New York: Hacker Art Books.

Riederer, J., 2007. Die metallurgische Zusammensetzung der Kupfer- und Bronzefunde aus Kalapodi. *In*: R.C.S. Felsch, ed. *Kalapodi. Ergebnisse der Ausgrabungen im Heiligtum der Artemis und* *des Apollon von Hyampolis in der antiken Phokis. Band II*. Mainz am Rhein: Verlag Philipp von Zabern, 390–422.

Risberg, C., 1992. Metal-Working in Greek Sanctuaries. *In*: T. Linders and B. Alroth, eds. *Economics of Cult in the Ancient Greek World, Proceedings of the Uppsala Symposium 1990*. Uppsala, 33–40.

Risberg, C., 1997. Evidence of Metal Working in Early Greek Sanctuaries. *In*: C. Gillis, C. Risberg, and B. Sjöberg, eds. *Trade and Production in Premonetary Greece: Production and the Craftsman. Proceedings of the 4th and 5th International Workshops, Athens 1994 and 1995*. Jonsered: Paul Åströms Förlag, 185–196.

Robbiola, L., Blengino, J.M., and Fiaud, C., 1998. Morphology and Mechanisms of Formation of Natural Patinas on Archaeological Cu-Sn Alloys. *Corrosion Science*, 40 (2), 2083–2111.

Robbiola, L., Pereira, N., Thaury, K., Fiaud, C., and Labbé, J.-P., 1998. Decuprification Phenomenon of Cu-Sn Alloys in Aqueous Solution in Nearly Neutral pH Conditions. *In*: P.R.S. Moorey and L. Robbiola, eds. *Metal 98*. London: James and James, 136–144.

Robbiola, L. and Portier, R., 2006. A global approach to the authentication of ancient bronzes based on the characterisation of the alloy-patina-environment system. *Journal of Cultural Heritage*, 7, 1–12.

Rolley, C., Philipakis, R., Photou, E., and Varoufakis, G., 1983. Bronzes grecs et orientaux: Influences et apprentissages. *BCH*, 107, 111–132.

Rowlands, M., 1993. The role of memory in the transmission of culture. *World Archaeology*, 25 (2), 141–151.

Rupp, D.W., 1983. Reflections on the Develoment of Altars in the Eighth century BC. *In*: R. Hägg, ed. *The Greek Renaissance of the Eighth Century BC: Tradition and Innovation*. Stockholm: Paul Åströms Förlag, 101–107.

Rutter, J.B., 1993. Review of Aegean prehistory II: The Prepalatial Bronze Age of the southern and central Greek mainland. *American Journal of Archaeology*, 97, 758–774.

De Ryck, I., Adriaens, A., and Adams, F., 2005. An overview of Mesopotamian bronze metallurgy during the 3rd millennium BC. *Journal of Cultural Heritage*, 6 (3), 261–268.

Di Salvatore, M., 1994. Ricerche sul Territorio di Pherai. Insediamenti, Difese, Vie e Confini. *In*: B. Helly, ed. *La Thessalie: Quinze Années de Recherches Archéologiques, 1975-1990. Bilans et Perspectives. Actes du Colloque International, Lyon, 17-22 Avril 1990, vol. B.* Athens: Ministry of Culture, 93–124.

Sampson, A., 1985. *Manika: an Early Bronze Age settlement*. Athens.

Sayre, E.V., Yener, K.A., and Joel, E.C., 1992. Statistical evaluation of the presently accumulated lead isotope data from Anatolia and surrounding regions. *Archaeometry*, 34 (1), 73–105.

Schacter, D.L., ed., 1995. *Memory distortion: how minds, brains, and societies reconstruct the past*. Cambridge, Massachusetts: Harvard University Press.

Schaeffer-Forrer, C.F.A., Zwicker, U., and Nigge, K., 1982. Untersuchungen an metallishcen Werkstoffen und Schlacken aus dem Bericht von Ugarit. *Mikrochimica Acta*, 77 (1), 35–61.

Schallin, A.-L., 1997. Metallurgy, a Divine Affair? *In*: C. Gillis, C. Risberg, and B. Sjöberg, eds. *Trade and Production in Premonetary Greece: Production and the Craftsman. Proceedings of the 4th and 5th International Workshops, Athens 1994 and 1995*. Jonsered: Paul Åströms Förlag, 139–171.

Schiffer, M.B., ed., 2001. *Anthropological Perspectives on Technology*. Albuquerque: University of New Mexico.

Schneider, G., 1989. Bronze Casting at Olympia in Classical Times. *In*: S.J. Fleming and H.R. Schenck, eds. *History of Technology: The Role of Metals, vol. 6*. Philadelphia: MASCA, The University Museum, University of Pennsylvania, 17–24.

Schuiling, R.D., 1967. Tin belts on the continents around the Atlantic Ocean. *Economic Geology*, 62, 540–550.

Scott, D.A., 1985. Periodic Corrosion Phenomena in Bronze Antiquities. *Studies in Conservation*, 30 (2), 49–57.

Scott, D.A., 1990. Bronze disease: a review of some chemical problems and the role of relative humidity. *Journal of the American Institute for Conservation*, 29 (2), 193–206.

Scott, D.A., 1991. *Metallography and Microstructure of Ancient and Historic Metals*. LA: The Getty Conservation Institute.

Scott, D.A., 2002. *Copper and Bronze in Art: corrosion, colorants, conservation*. LA: The Getty Conservation Institute.

Scott, D.A., 2012. *Ancient Metals: Microstructure and Metallography, Volume I Copper and Copper Alloys*. 2nd ed. Los Angeles: Conservation Science Press.

Scott, M., 2010. *Delphi and Olympia: the spatial politics of Panhellinism in the Archaic and Classical periods*. Cambridge: Cambridge University Press.

Selwyn, L.S., 2004. *Metals and Corrosion: a handbook for the conservation professional*. Canada: Canadian Conservation Institute.

Shackley, M.S., 2011a. X-ray fluorescence spectrometry in twenty-first century archaeology. *In*: M.S. Shackley, ed. *X-Ray Fluorescence Spectrometry (XRF) in Geoarchaeology*. New York: Springer, 1–6.

Shackley, M.S., 2011b. An introduction to X-ray fluorescence (XRF) analysis in archaeology. *In*: M.S. Shackley, ed. *X-Ray Fluorescence Spectrometry (XRF) in Geoarchaeology*. New York: Springer, 7–43.

Shennan, S., 2008. Evolution in Archaeology. *Annual Review of Anthropology*, 37, 75–91.

Sherratt, S. and Sherratt, A., 1993. The Growth of the Mediterranean Economy in the Early First Millennium BC. *World Archaeology*, 24 (3), 361–378.

Shoukang, Z. and Tangkun, H., 1993. Studies on ancient Chinese mirrors and other bronze artefacts. *In*: S. La Niece and P.T. Craddock, eds. *Metal Plating and Patination*. Oxford: Butterworth-Heinemann, 50–62.

Shugar, A.N., 2013. Portable X-ray Fluorescence and Archaeology: Limitations of the Instrument and Suggested Methods to Achieve Desired Results. *In*: R.A. Armitage and J.H. Burton, eds. *Archaeological Chemistry VIII*. Washingtong D.C.: American Chemical Society, 173–193.

Shugar, A.N. and Mass, J.L., eds., 2012. *Handheld XRF for Art and Archaeology*. Leuven: Leuven University Press.

Sillar, B. and Tite, M.S., 2000. The Challenge of 'Technological Choices' for Materials Science Approaches in Archaeology. *Archaeometry*, 42 (1), 2–20.

Sinn, U., 1993. Greek Sanctuaries as Places of Refuge. *In*: N. Marinatos and R. Hägg, eds. *Greek Sanctuaries: New Approaches*. London and NY: Routledge, 88–109.

Sinn, U., 1996. The Influence of Greek Sanctuaries on the Consolidation of Economic Power. *In*: P. Hellström and B. Alroth, eds. *Religion and Power in the Ancient Greek World*. Uppsala, 67–74.

Skarpelis, N., 2003. Potential Tin Sources in the Aegean. *In*: A. Giumlia-Mair and F. Lo Schiavo, eds. *The Problem of Early Tin*. Oxford: Archaeopress, 159–164.

Smith, C.S., 1965. The interpretation of microstructures of metallic artifacts. *In*: *Application of science in examination of works of art. Proceedings of the seminar: September 7-16, 1965, conducted by the Research Laboratory, Museum of Fine Arts*. Boston, Massachusetts: Museum of Fine Arts, 20–52.

Snodgrass, A., 1971. *The Dark Age of Greece: an archaeological survey of the 11th to the 8th c. BC*. Edinburgh: Edinburg University Press.

Snodgrass, A., 1990. The Economics of Dedication at Greek Sanctuaries. *Scienze dell' Antichita*, 3-4, 287–294.

Snodgrass, A., 2000. *The Dark Age of Greece: an archaeological survey of the 11th to the 8th c. BC (2nd edition)*. Edinburgh: Edinburgh University Press.

Snodgrass, A.M., 1981. *Archaic Greece: The Age of Experiment*. University of California Press.

Sordi, M., 1997. I tagoi tessali come suprema magistratura militare de koinon tessaliko. *Topoi*, 7, 177–182.

Soto, L., Franey, J.P., Graedel, T.E., and Kammlott, G.W., 1983. On the corrosion resistance of certain ancient chinese bronze artifacts. *Corrosion Science*, 23, 241–250.

Souyoudzoglou-Haywood, C., 1999. *The Ionian Islands in the Bronze Age and Early Iron Age: 3000-800 BC*. Liverpool: Liverpool University Press.

Spät, E., 2009. The role of the peacock 'Sanjak' in Yezidi religious memory: maintaining Yezidi oral tradition. *In*: I. Barbiera, A.M. Choyke, and J.A. Rasson, eds. *Materializing memory: archaeological material culture and the semantics of the past*. Oxford: Archaeopress, 105–116.

Speakman, R.J. and Shackley, M.S., 2013. Silo science and portable XRF in archaeology: a response to Frahm. *Journal of Archaeological Science*, 40 (2), 1435–1443.

Sprawski, S., 2006. Jason of Pherai, a Leader of the Thessalians. *In*: *Hypereia 4*. 203–210.

Stahlin, F., 2002. *Η Αρχαία Θεσσαλία*. Thessaloniki: Kyriakidi.

Staniaszek, B.E.P. and Northover, J.P., 1983. The Properties of Leaded Bronze Alloys. *In*: A.A. Spinall and S.E. Warren, eds. *The Proceedings of the 22nd Symposium on Archaeometry, 30 March - 3 April 1982*. Bradford, W. Yorks: Schools of Physics and Archaeological Sciences, University of Bradford, 262–272.

Stavrakoudi, K., 2006. Ελληνιστική Αγροικία στην Περιφέρεια των Αρχαίων Φερών. *In*: *Hypereia 4*. Volos: Ministry of Culture, 183–201.

Stech, T. and Pigott, V.C., 1986. The metals trade in southwest Asia in the third millennium BC. *British Institute for the Study of Iraq*, 48, 39–64.

Steiner, L. and Zelizer, B., 1995. Competing memories. Reading the past against the grain: The shape of memory studies. *Critical Studies in Mass Communication*, 12 (2), 213–239.

Stewart, E.M. and Stewart, J.R., 1950. *Vounous 1937-38: Field Report on the Excavations Sponsored by the British School of Archaeology at Athens, Vol. 14*. CWK Gleerup.

Stiebing, W.H., 1980. The end of the Mycenaean Age. *The Biblical Archaeologist*, 43, 7–21.

Stoop, M.W., 1972. Santuario sul Timpone della Motta; bronzi, terrecotte e ceramiche. *Atti e Memorie della Societa Magna Grecia*, 11-12, 38–66.

Stos-Gale, Z., 1992. The origin of metal objects from the Early Bronze Site of Thermi on the island of Lesbos. *Oxford Journal of Archaeology*, 11 (2), 155–177.

Stos-Gale, Z. and Gale, N.H., 2006. Lead isotope and chemical analyses of slags from Chrysocamino. *Hesperia Supplements*, 36, 299–319.

Stos-Gale, Z. and Gale, N.H., 2010. Bronze Age metal artefacts found on Cyprus - metal from Anatolia and the Western Mediterranean. *Trabajos de Prehistoria*, 67, 389–403.

Stos-Gale, Z. and Gilmore, G.R., 1984. Early Bronze Age Trojan metal sources and Anatolians in the Cyclades. *Oxford Journal of Archaeology*, 3 (3), 23–44.

Strange, J., 1987. The transition from the Bronze Age to the Iron Age in the eastern Mediterranean and the emergence of the Israelite state. *Scandinavian Journal of the Old Testament: An International Journal of Nordic Theology*, 1 (1), 1–19.

Strøm, I., 1992. Obeloi of Pre or Proto-Monetary Value in Greek Sanctuaries. *In*: T. Linders and B. Alroth, eds. *Economics of Cult in the Ancient Greek World, Proceedings of the Uppsala Symposium 1990*. Uppsala, 41–51.

Tandy, D.W., 1997. *Warriors into traders: the power of the market in Early Greece*. Berkeley and Los Angeles: University of California Press.

Taylor, J.W., 1983. Erzgebirge tin: a closer look. *Oxford Journal of Archaeology*, 2 (3), 295–298.

Theocharis, D.R., 1967. *Η Αυγή της Θεσσαλικής Προϊστορίας: Αρχή και Πρώιμη Εξέλιξη της Νεολιθικής*. Volos: Filarchaios Etaireia Volou.

Thornton, C.P. and Ehlers, C.B., 2003. Early brass in the ancient Near East. *IAMS*, 23.2003, 3–8.

Thornton, C.P., Lamberg-Karlovsky, C.C., Liezers, M., and Young, M.M., 2002. On Pins and Needles: Tracing the Evolution of Copper-base Alloying at Tepe Yahya, Iran, via ICP-MS Analysis of Common-place Items. *Journal of Archaeological Science*, 29 (12), 1451–1460.

Thornton, C.P., 2007. Of brass and bronze in prehistoric southwest Asia. *In*: S. La Niece, D.R. Hook, and P.T. Craddock, eds. *Metals and Mines: Studies in Archaeometallurgy*. London: Archetype, 189–201.

Tilley, C., Keane, W., Küchler, S., Rowlands, M., and Spyer, P., eds., 2006. *Agency, biography and objects*. London: Sage.

Tite, M.S., 2002. Archaeological Collections: Invasive Sampling versus Object Integrity. *PIA*, 13, 1–5.

Tite, M.S., Merriman, N., Rehren, T., Schadla-Hall, T., and Walker Tubb, K., 2002. Invasive Sampling vs. Object Integrity. *Papers from the Insitute of Archaeology*, 13, 1–5.

Tizzoni, M., Cucini Tizzoni, C., Rebay, G., and Riccardi, M.P., 2008. Archaeometallurgical researches in the Othris Mountains, Greece. *In*: Y. Fakorelis, N. Zacharias, and K. Polikreti, eds. *Proceedings of the 4th International Symposium of the Hellenic Society for Archaeometry*. Oxford: Archaeopress, 535–544.

Trevelyan, A.M., 2004. *Miskwabik: Metal of Ritual. Metallurgy in Precontact Eastern North America*. Kentucky: The University Press of Kentucky.

Trigger, B., 2006. *A History of Archaeological Thought*. 2nd ed. Cambridge: Cambridge University Press.

Tykot, R.H. and Vianello, A., 2015. Scientific analysis of archaeological objects in museums: modern technologies and limitations of the collections [session SA19]. *In*: *Annual meeting of the European Association of Archaeologists, Glasgow 2-5 September 2015*.

Tylecote, R.F., 1979. The Effect of Soil Conditions on the Long-term Corrosion of Buried Tin-bronzes and Copper. *Journal of Archaeological Science*, 6, 345–68.

Tylecote, R.F., 1983. The behaviour of lead as a corrosion resistan medium undersea and in soils. *Journal of Archaeological Science*, 10 (4), 397–409.

Tylecote, R.F., 1992. *A History of Metallurgy*. 2nd ed. London: Institute of Materials.

Tylecote, R.F., Ghaznavi, H.A., and Boydell, P.J., 1977. Partitioning of trace elements between ores, fluxes, slags and metal during the smelting of copper. *Journal of Archaeological Science*, 4, 305–333.

Tzachili, I., 2008. An addendum: were there sources of metal ores on Crete or not? *In*: I. Tzachili, ed. *Aegean Metallurgy in the Bronze Age. Proceedings of the International Symposium held at the University of Crete, Rhethymnon, Greece, on November 19-21, 2004*. Athens: Ta Pragmata Publications, 327–329.

Tziafalias, A. and Zaouri, A., 2003. Από τη Βόρεια Περραιβία ως την Αρχαία Κραννώνα: Νεκροταφεία της Πρώιμης Εποχής του Σιδήρου. *In*: N. Kyparissi-Apostolika, M. Papakonstantinou, and M. Pantelidou-Gofa, eds. *The Periphery of the Mycenaean World, Proceedings of the 2nd International Interdisciplinary Colloquium, Lamia 1999*. Athens: Ministry of Culture, 143–152.

Ucko, P.J., 1989. Foreward. *In*: S.E. van der Leeuw and R. Torrence, eds. *What's new? a closer look at the process of innovation*. London: Unwin Hyman, ix–xiv.

Uribe Villegas, M.A. and Martinón-Torres, M., 2012. Composition, colour and context in Muisca votive metalwork (Colombia, AD 600–1800). *Antiquity*, 86, 772–791.

Valera, R.G. and Valera, P.G., 2003. Tin in the Mediterranean Area: History and Geology. *In*: A. Giumlia-Mair and F. Lo Schiavo, eds. *The Problem of Early Tin*. Oxford: Archaeopress, 3–14.

Vernon, W.W., 1990. New archaeometallurgical perspectives on the Old Copper industry of North America. *In*: N.P. Lasca and J. Donahue, eds. *Archaeological geology of North America, Centennial Special Volume 4*. Boulder: Geological Society of America, 499–512.

Vokotopoulou, I., 1986. *Vitsa: The cemeteries of a Molossian settlement (in Greek)*. Athens: TAP.

Vokotopoulou, I., 1990. *The tombs of Aeneia (in Greek)*. Athens: TAP.

Vokotopoulou, I., 1992. Poseidi. *In*: *Archaeological Work of Macedonia and Thrace 6*. 443–450.

Voreadis, G.D., 1954. *Geological and mining research in Thasos*. Athens: IGME.

Voyatzis, M.E., 1990. *The Early Sanctuary of Athena Alea at Tegea and other Archaic Sanctuaries in Arkadia*. Göteborg: Paul Åströms Förlag.

Wagner-Hasel, B., 2006. Gift Exchange: Modern Theories and Ancient Attitudes. *In*: S. Deger-Jalkotzy and I. Lemos, eds. *Ancient Greece: from the Mycenean palaces to the Age of Homer*. Edinburgh: Edinburgh University Press, 257–269.

Wainwright, G.A., 1944. Early tin in the Aegean. *Antiquity*, 18 (70), 57–64.

Waldbaum, J.C., 1978. *From bronze to iron: the transition from the Bronze Age to the Iron Age in the eastern Mediterranean*. Göteborg: Paul Åströms Förlag.

Waldbaum, J.C., 1994. Early Greek Contacts wth the Southern Levant, ca. 1000-600 BC: The Eastern Perspective. *Bulletin of the American Schools of Oriental Research*, 293, 53–66.

Wang, J., Xu, C., and Lv, G., 2006. Formation Processes of CuCl and Regenerated Cu Crystals on Bronze Surfaces in Neutral and Acidic Media. *Applied Surface Science*, 252, 6294–6303.

Wang, Q. and Ottaway, B.S., 2004. *Casting experiments and microstructure of archaeologically relevant bronzes*. Oxford: Archaeopress.

Wartenberg, U., 1994. The History and Coinage of Alexander of Pherae. *In*: D. Karamberopoulos and E. Kakavogiannis, eds. *Hypereia 2, vol. 1*. 151–159.

Watts, C., 2013. *Relational archaeologies: humans, animals, things*. New York: Routledge.

Weeks, L., 1999. Lead isotope analyses from Tell Abraq, United Arab Emirates: new data regarding the 'tin problem' in Western Asia. *Antiquity*, 73, 49–64.

Van Wees, H., 1998. The Law of Gratitude: Reciprocity in Anthropological Theory. *In*: C. Gill, N. Postlethwaite, and R. Seaford, eds. *Reciprocity in Ancient Greece*. Oxford: Oxford University Press, 13–49.

Weiss, B., 1982. The decline of Late Bronze Age civilization as a possible responce to climate change. *Climatic Change*, 4 (2), 173–198.

Wertime, A., 1978a. The search for ancient tin: the geographic and historic boundaries. *In*: A.D. Franklin, J.S. Olin, and T.A. Wertime, eds. *The Search for Ancient Tin*. Washingtong D.C.: Smithsonian Museum, 1–6.

Wertime, A., 1978b. Introduction. *In*: A.D. Franklin, J.S. Olin, and T.A. Wertime, eds. *The Search for Ancient Tin*. Washingtong D.C.: Smithsonian Museum, viii.

Westlake, H.D., 1935. *Thessaly in the 4th century BC*. London: Methuen.

Whitehead, D., 1977. *The ideology of the Athenian Metic*. Cambridge.

Whitley, J., 1991a. *Style and Society in Dark Age Greece: the changing face of a pre-literate society 1100-700 BC*. Cambridge: Cambridge University Press.

Whitley, J., 1991b. Social diversity in Dark Age Greece. *BSA*, 86, 341–365.

Whitley, J., 2006. Classical Art and Human Agency: a tale of two objects in the fifth century Greece. *In*: N.C. Stampolidis, ed. *Γενέθλιον. Αναμνηστικός Τόμος για τη Συμπλήρωση Είκοσι Χρόνων Λειτουργίας του Μουσείου Κυκλαδικής Τέχνης*. Athens: Goulandris Foundation, 227–236.

Wilamowitz, U. von, 1931. *Der Glaube der Hellenen*. Berlin: Weidmann.

Williams, H., ed., 2003. *Archaeologies of remembrance: death and memory in past societies*. New York; London: Kluwer Academic/Plenum Publishers.

Willies, L., 1992. Reply to Pernicka et al.: comment on the discussion of ancien tin sources in Anatolia. *Journal of Mediterranean Archaeology*, 5, 99–103.

Yakar, J., 1984. Regional and local schools of metalwork in Early Bronze Age Anatolia, Part 1. *Anatolian Studies*, 34, 59–86.

Yener, K.A. and Goodway, M., 1992. Response to Mark E. Hall and Sharon R. Steadman, 'Tin and Anatolia: another look'. *Journal of Mediterranean Archaeology*, 5, 77–90.

Yener, K.A. and Özbal, H., 1987. Tin in the Turkish Taurus Mountains: The Bolkardağ mining district. *Antiquity*, 61, 220–226.

Yener, K.A., Özbal, H., Kaptan, E., Pehlivan, A.N., and Goodway, M., 1989. An Early Bronze Age source of tin ore in the Taurus Mountains, Turkey. *Science*, 244, 200–203.

Yener, K.A. and Vandiver, P.B., 1993. Tin processing at Göltepe, an Early Bronze Age site in Anatolia. *American Journal of Archaeology*, 97, 207–238.

Yi, W., Budd, P., McGill, R.A.R.S., Young, M.M., Halliday, A.N., Haggerty, R., Scaife, B., and Pollard, A.M., 1999. Tin isotope studies of experimental and prehistoric bronzes. *In*: A. Hauptmann, E. Pernicka, T. Rehren, and Ű. Yalçin, eds. *The beginnings of metallurgy*. Bochum: Deutsches Bergbau-Museum, 285–290.

Zaccagnini, C., 1983. Patterns of Mobility among Ancient Near Eastern Craftsmen. *Journal of Near Eastern Studies*, 42 (4), 245–246.

Zaccagnini, C., 1990. The Transition from Bronze to Iron in the Near East and in the Levant: Marginal Notes. *Journal of the American Oriental Society*, 110 (3), 493–502.

Zacharias, N., Michael, C.T., Georgakopoulou, M., Kilikoglou, V., and Bassiakos, Y., 2006. Quartz TL Dating on Selected Layers from Archaeometallurgical Kiln Fragments: A Proposed Procedure to Overcome Age Dispersion. *Geochronometria*, 25, 29–35.

Zacharias, N., Orfanou, V., Rizou-Kalakona, M., Georgakopoulou, M., Bassiakos, Y., and Michael, C.T., 2008. Thermoluminescence and Optically Stimulated Luminescence Studies of Early Cycladic Metallurgical Ceramics from Seriphos, Greece. *In*: *Poster presented in: 37th International Symposium on Archaeometry, 12-16 May 2008, Siena*. Siena.

Zimmermann, J.-L., 1989. *Les chevaux de bronze dans l'art géometrique grec*. Mainz.

Appendices

Appendix I. Typology and dating of the sample

Certain artefact types presented in the analysed sample are considered in more detail for a more comprehensive understanding of the typological and chronological circumstances of the assemblage from Pherae. Below, artefacts in the sample typologically studied in the past or for the needs of this study are considered, as well as additional contexts with contemporary dating. Amongst the objects recovered from Pherae and sampled which involve more elaborate typological sequences are the fibulae, the pendants, including the bird pendants, and the rings. Furthermore, typological investigation of the Pheraean bronzes promotes the discussion of both locally produced objects and imports, as well as local imitations of foreign types. Thus, macroscopic investigation of the sample, points to specific artefact types being related to specific regional workshops or metalworking traditions from different parts of mainland Greece and elsewhere such as from northern, central and southern mainland Greece, or Anatolia. Finally, the dating of the material discussed below was based on parallel finds from additional Early Iron Age sites from mainland Greece which include the Protogeometric cemetery of Vitsa and the Archaic tombs of Aeneia (Vokotopoulou 1986, 1990), and the Early Iron Age cemetery at Agrosykia (Chrysostomou 2007) in northern Greece, the sanctuaries of Athena Alea at Tegea in the Peloponnese, Olympia (Philipp 1981), Isthmia (Raubitschek 1998) and Kalapodi (Felsch 2007); for the fibulae, and decorative ornaments and pendants the typologies established by Kilian (1975) and Kilian-Dirlmeier (1979, 1985) and for the pins the work of Jacobsthal (1956) have been also used as reference collections; finally, Bouzek's (e.g. 1985, 1997) work on the Macedonian bronzes was **also incorporated.**

I.1 Fibulae

A total of 119 fibulae have been included in the sample of both surface and invasive analyses. The reasons for putting emphasis on this particular artefact type are twofold. Firstly, fibulae are present in the assemblage with more occurrences than any other artefact type with thousands of objects recovered and, thus even under a stratified sampling strategy they would still form the largest group. Secondly, they have been favoured during sampling due to their specific morphologic and decoration features which could be used in order to attributed them to different traditions or 'workshops' and, thus, would promote the discussion for the possibility of different metallurgical traditions being practiced. Additionally, on the basis of their form and particular typology it was possible to estimate their dating. For the classification and categorisation of the fibulae in the sample below the already published works of Kilian (1975) and Blinkenberg (1926) have been considered as they both include detailed accounts of the fibulae which cover most of the fibulae types in circulation during the Early Iron Age in Greece.

The fibulae in the sample have been broadly categorised in main clusters, namely those of the Thessalian, Epirotic, and Helladic type, while the latter includes two sub-types, i.e. the Helladic proper and Attic-Boeotian ones. Fewer spectacle fibulae with a suggested northern origin from the northeast whose occurrence in mainland Greece dates to the 10th century BC onwards have been also included (Bouzek 1997, p. 115) (Figure I.1). Epirotic and Thessalian fibulae are amongst the most frequently seen both in the excavated assemblage and in the analysed sample. Attic-Boeotian and Helladic, and spectacle fibulae also less frequently found but they are still relatively often found, whereas, fewer fibulae from Asia Minor and Anatolia have been recovered are represented in the sample with one fibulae (the Phrygian fibula M 1413). Finally, certain fibulae which consist of a thin metal wire bow of with round or square cross-section which are represented in the sample with three fibulae (M 775, M 776.1 & 2) are more difficult to be typologically characterised due to their simple bow and the lack of any further decoration. Consequently, they could be linked to either Sub-Mycenaean or with an origin from south Italy on the basis of Kilian's drawings.

In the table below, the typology of the fibulae in the sample according to published data by Kilian (1975) and Blinkenberg (1926) are included, while the dating follows Kilian's catalogue. For pictures and more detailed descriptions of the fibulae see Appendix III.

*Table I.1. Summary of the fibulae (*VO or absolute numbers in the Analyses No. indicate pXRF and EPMA analyses respectively; n.a.= not available)*

Inv. No.	Analyses No. *	Type	Kilian	Blinken-berg	Alloy	Date
M 2265	VO022	Attic-Boeotian	B II	VIII	bronze	late 8th c.
M 1315.1	VO04	Attic-Boeotian	A IIa	VIII	bronze	late 8th c.
M 1225	VO077	Attic-Boeotian	B Ib	VIII	bronze	late 8th c.
M 1315.2	VO005	Epirotic	K Id	V	bronze	late 8th c.
M 1794	VO013	Epirotic	K Ib	V	bronze	8th c.
M 2125	VO020	Epirotic	K Ib/IIb	V	copper	8th c.
M 1585.2	VO026	Epirotic	K Ib	V	leaded bronze	8th c.
M 339	VO031	Epirotic	J IIb	V	bronze	8th-7th c.
M 1812.3	VO036	Epirotic	K IIa	V	bronze	8th c.
M 1812.2	VO038	Epirotic	K IIa	V	bronze	8th c.
M 2104	VO039	Epirotic	K IIa	V	bronze	8th c.
M 2111	VO040	Epirotic	K IIa	V	bronze	8th c.
M 2230	VO062	Epirotic	K Ib	V	bronze	8th c.
M 2229	VO064	Epirotic	K Ib	V	bronze	8th c.
M 2234	VO065	Epirotic	K Ia	V	leaded bronze	8th c.
M 2226	VO072	Epirotic	K Ia	V	bronze	8th c.
M 1731.2	VO075	Epirotic	K Ia/IIa	V	bronze	8th c.
M 2114	VO076	Epirotic	K Ib	V	leaded bronze	8th c.
M 2233.2	VO083A	Epirotic	K Ia	V	bronze	8th c.
M 3362	VO086	Epirotic	K Ia	V	bronze	8th c.
M 1661.4	VO089	Epirotic	K Ib/IIb	V	bronze	8th c.

M 1661.7	VO090	Epirotic	K Ib/IIb	V	bronze	8^{th} c.
M 1661.1	VO092	Epirotic	K Ib	V	leaded bronze	8^{th} c.
M 1661.3	VO093	Epirotic	K Ib	V	leaded bronze	8^{th} c.
M 1661.5	VO094	Epirotic	K IIb	?	leaded bronze	8^{th} c.
M 1661.2	VO095	Epirotic	K Ib/IIb’	V	/’;>bronze	8^{th} c.
M 1815.4	VO096	Epirotic	C IIIk	V	bronze	early 8^{th} c.
M 1815.3	VO097	Epirotic	K Ib	V	bronze	8^{th} c.
M 1815.1	VO098	Epirotic	K Ia	V	bronze	8^{th} c.
M 1735.4	VO102	Epirotic	K Ib/IIb	V	bronze	8^{th} c.
M 1735.1	VO103	Epirotic	K Ib	V	bronze	8^{th} c.
M 1735.2	VO104	Epirotic	K Ib	V	copper	8^{th} c.
M 1735.3	VO105	Epirotic	K Ib	V	bronze	8^{th} c.
M 1734.1	VO106	Epirotic	K Ib	V	leaded bronze	8^{th} c.
M 1734.3	VO107	Epirotic	K Ib/IIb	V	leaded bronze	8^{th} c.
M 1734.2	VO108	Epirotic	K Ib	V	bronze	8^{th} c.
M 1734.4	VO109	Epirotic	K Ib	V	bronze	8^{th} c.
M 1734.5	VO110	Epirotic	K Ib	V	leaded bronze	8^{th} c.
M 2232.2	VO115A	Epirotic	K Ia	V	bronze	8^{th} c.
M 1731.4	VO117	Epirotic	K IIa	V	leaded bronze	8^{th} c.
M 1731.4	VO117A	Epirotic	K IIa	V	leaded bronze	8^{th} c.
M 1731.3	VO118	Epirotic	K IIa	V	leaded bronze	8^{th} c.
M 1731.1	VO119	Epirotic	K IIa	V	bronze	8^{th} c.
M 745.1	VO120	Epirotic	K IIa	V	bronze	8^{th} c.
M 745.3	VO121	Epirotic	K Ia	V	leaded bronze	8^{th} c.
M 745.5	VO122	Epirotic	K Ia	V	leaded bronze	8^{th} c.
M 745.4	VO123	Epirotic	K Ia	V	leaded bronze	8^{th} c.
M 745.2	VO124	Epirotic	K Ia	V	leaded bronze	8^{th} c.
AE 811	VO162	Epirotic	K Ib/IIb	V	bronze	8^{th} c.
M 3367.2	VO168 & 10	Epirotic	K Ia	V	bronze	8^{th} c.
M 3367.1	VO169 & 8	Epirotic	K IIa	V	bronze	8^{th} c.
M 1314.1	VO170 & 20	Epirotic	K Ib/IIb	V	bronze	8^{th} c.
M 1314.2	VO171 & 25	Epirotic	K Ib	V	bronze	8^{th} c.
AE 465	VO196	Epirotic	J IIb	V	bronze	8^{th}-7^{th} c.
M 338	VO009	Helladic		VII	bronze	n.a.
M 3298.1	VO024	Helladic	E II	VII	bronze	n.a.
M 3298.2	VO025	Helladic	E II	VII	bronze	n.a.
M 214.2	VO034	Helladic	E I	VII	bronze	late 8^{th} c.
M 262	VO035	Helladic	F IIIc	VII	bronze	7^{th} c.
M 2136	VO079	Helladic	D I	VII	bronze	early 8^{th} c..
M 1928	VO084	Helladic	E I	VII	bronze	late 8^{th} c.
M 1739.2	VO164	Helladic	E IIIb	VII	bronze	late 8^{th} c.
M 1739.3	VO165	Helladic	E I	VII	bronze	late 8^{th} c.
M 1739.1	VO166	Helladic	D I	VII	bronze	early 8^{th} c.
M 1739.4	VO167	Helladic	E I	VII	bronze	late 8^{th} c.
M 1413	VO063	Phrygia	Phrygian	XII	bronze	8^{th}-7^{th} c.
M 776.1	VO027	simple sheet bow	Italian?		copper	n.a.

M 776.2	VO028	simple sheet bow	Italian?		copper	n.a.
M 775	VO033	simple sheet bow	Italian?		copper	n.a.
M 1877	VO012	spectacle	C	XIV	bronze	early 8^{th} c.
M 2222	VO014	spectacle	B II	XIV	bronze	late 8^{th}-early 7^{th} c
M 2096	VO078	spectacle	B II	XIV	bronze	late 8^{th}-early 7^{th} c
M 1646	VO085	spectacle	B II	XIV	bronze	late 8^{th}-early 7^{th} c
M 1666.2	VO001	Thessalian	D IIIk	VI	bronze	8^{th}-7^{th} c.
M 1666.3	VO002	Thessalian	D IIIk	VI	bronze	8^{th}-7^{th} c.
M 1666.1	VO003	Thessalian	D IIIk	VI	leaded bronze	8^{th}-7^{th} c.
AE 275	VO006	Thessalian	C XI	VI	bronze	late 8^{th} c.
M 363	VO011	Thessalian	D Ib	VI	bronze	8^{th} c.
M 2228	VO018	Thessalian	C XI	VI	bronze	late 8^{th} c.
M 2116	VO019	Thessalian	C IIIk	VI	bronze	early 8^{th} c.
M 2109	VO023	Thessalian	A IIIa.b	VI	bronze	late 8^{th} c.
M 776.3	VO029	Thessalian	A IIIa.b	VI	copper	late 8^{th} c.
M 3268	VO030	Thessalian	B IIIa	VI	bronze	late 8^{th} c.
M 282	VO032	Thessalian	A-K	VI	leaded bronze	n.a.
M 1812.1	VO037	Thessalian	A IIa	VI	bronze	late 8^{th} c.
AE 726	VO041	Thessalian	D VIb	VI	bronze	late 8^{th} c.
M 2097	VO047	Thessalian		VI	bronze	late 8^{th} c.
M 2099	VO049	Thessalian	C IIb	VI	bronze	late 8^{th}-early 7^{th} c
M 757	VO067	Thessalian	C III	VI	bronze	7^{th} c.
M 1909	VO073	Thessalian	D Ip	VI	bronze	7^{th} c.
M 8084/2055	VO074	Thessalian	B IIIa	VI	bronze	late 8^{th} c.
M 2237	VO080	Thessalian	D IIIc	VI	bronze	late 8^{th}-early 7^{th} c
M 2105	VO087	Thessalian	A IIa	VI	copper	late 8^{th} c.
M 538	VO088	Thessalian	C VII	VI	bronze	late 8^{th} c.
M 226.2	VO099	Thessalian	D IIIq	VI	bronze	late 8^{th} c.
M 226.1	VO100	Thessalian	D IIIq	VI	leaded bronze	late 8^{th} c.
M 1345.1	VO111	Thessalian	A IIa	VI	bronze	late 8^{th} c.
M 1345.2	VO112	Thessalian	A IIb	VI	bronze	late 8^{th} c.
AE 720	VO177	Thessalian	A X	VI	bronze	8^{th} c.
AE 626	VO178	Thessalian	B IIIa	VI	bronze	late 8^{th} c.
AE 843	VO180	Thessalian	B IIIa	VI	bronze	late 8^{th} c.
AE 585	VO182	Thessalian	D Ib	VI	copper	8^{th} c.
AE 738	VO195	Thessalian	B IIIp	VI	bronze	late 8^{th} c.
M 1815.2	34	non-diagnostic			bronze	n.a.
M 2106	VO017	non-diagnostic			bronze	n.a.
AE 740	VO0217	non-diagnostic			bronze	n.a.
AE 871	VO0218	non-diagnostic			copper	n.a.
M 2122.1	VO021A	non-diagnostic			bronze	n.a.
M 2122.2	VO021B	non-diagnostic			leaded bronze	n.a.
M 1843.1	VO050A	non-diagnostic, horse-shoe fibula			zinc-rich	n.a.
M 1843.2	VO050B	non-diagnostic			copper	n.a.
M 2117.1	VO051A	non-diagnostic			bronze	n.a.
M 2117.2	VO051B	non-diagnostic			copper	n.a.

M 2262	VO066	non-diagnostic	leaded bronze	n.a.
M 1661.6	VO091	non-diagnostic	leaded bronze	n.a.
M 1345.3	VO113	non-diagnostic	copper	n.a.
AE 661	VO151	non-diagnostic	bronze	n.a.
AE 650	VO190	non-diagnostic	bronze	n.a.

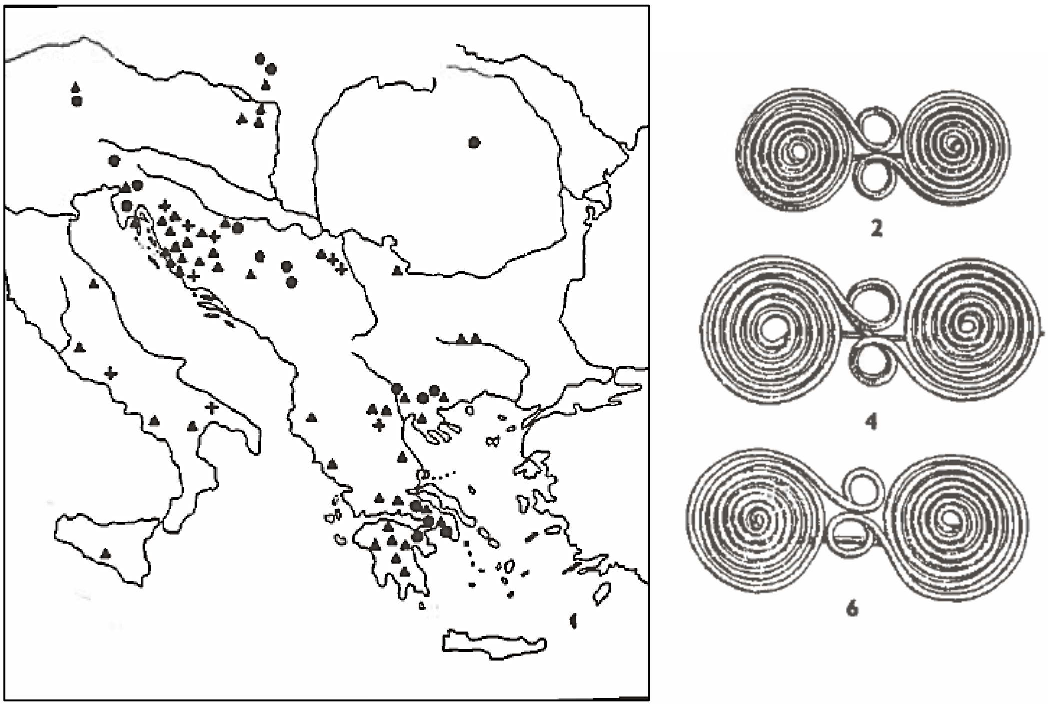


Figure I.1. Distribution map of the simple spectacle fibulae (after Andronikos 1969, Bouzek 1969, both in: 1997, fig. 118-119)

I.2 Rings

The group of rings is the second largest artefact group in both the excavated and the analysed assemblage. As opposed to the group of fibulae which in most cases have be attributed to specific typological features (see above I.1). In addition, this group is quite diverse too as rings of different types have had different uses. Thus, certain ring types could have been used as fingerings, as attachments to decorate the hair (see Vb spiral AE 899), but also as decorative ornaments in the form of pendants or used to form decorative chains (Figure 7.31). Despite the diverse features of the rings, the following typological categorisation has been conducted in order to highlight their common features even though some variation is still present (see also Chapter 7.3.2, Figure 7.30). Consequently, ring types present in the analysed sample have been broadly categorised into five different groups, i.e. Types I to V, while the last type (V) corresponds to the spiral rings.

I.2.1 Type I

Under Type I, rings of thin metal wire with round cross-section and often with open ends have been classified. Further, subdivision of this type was conducted after additional decoration features. Hence, Type Ia rings do not have any further decoration elements (Figure I.2), whereas type Ib which are also simple round wire rings have endings decorated with spirals (Figure I.3, Figure 3.6). Typical dimensions for Type Ia and Ib rings are diameters of approximately 2 cm and wire thickness of 0.1-0.2 cm.

I.2.1.1 Type Ia: simple cross-section (23)

Type Ia is the largest group in the sample analysed and consists of 22 rings, i.e. more than one in three analysed rings belongs to this Type. In addition, their simple form shows a particularly wide distribution across different chronological periods, and it is difficult to characterise chronologically any of these rings in more detail. The following rings are included in this subgroup:

1. 1310	6. AE 261	12. AE 654	18. AE 798
2. AE 103	7. AE 34.1	13. AE 733.1	19. AE 810
3. AE 113	8. AE 37	14. AE 760.2	20. AE 929
4. AE 246	9. AE 507	15. AE 765	21. AE 97
5. AE 26	10. AE 597	16. AE 784.1	22. AE 98
	11. AE 633.1 (?)	17. AE 796	

Figure I.2. Type Ia ring AE 103 with simple round cross-section and open ends

Figure I.3. Rings with spiral endings AE 754 (left) and AE 838 (right)

I.2.1.2 Type Ib: with wire rings with spiral endings (2)

Two rings with spiral endings are present in the sample, namely the rings AE 754 and AE 838 of narrow sheet and round cross sections (Kilian 1975, pl. 70, 13, 19-20). Parallels dating to the late 8th and early 7th centuries have been recovered in the cemetery of Vitsa (Vokotopoulou 1986, pl. 111, 2288a, 2448). Decoration-wise, the spiral endings resemble spiral decoration patterns present already from the late Submycenaean and Protogeometric periods, while the long survival of this pattern in the 7th century BC has been pointed out as notable by Votokopoulou (1986, p. 315). Parallel finds of Type Ib rings with either round or rhomboid cross-sections have been also recovered at the Protogeometric cemetery in Vitsa (Vokotopoulou 1986, pl. 111, 2288a, 2448). Overall, a long period of use for this type of ring is seen which covers most of the Early Iron Age in mainland Greece.

I.2.2 Type II

In Type II, also simple rings with no particular decoration features on their surface have been included. Nonetheless, their main difference from Type Ia rings is the shape of their cross-sections which instead of being round is either triangular for Type IIA or curved, plano-convex for Type IIb rings.

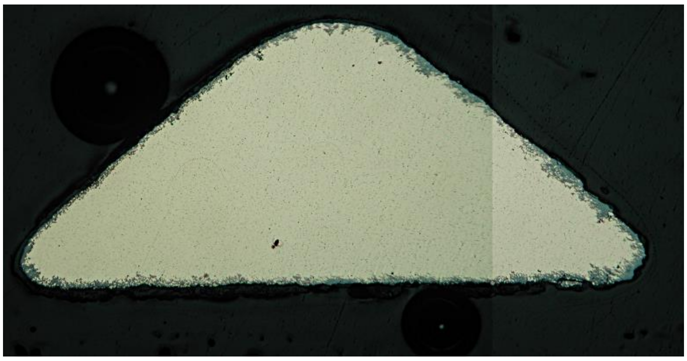


Figure I.4. Photomicrograph of Type IIa ring AE 459 with triangular cross-section

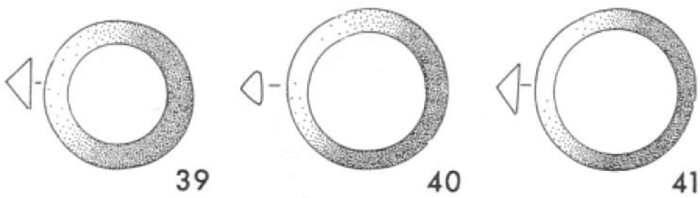


Figure I.5. Drawings of rings with triangular cross-section (Type IIa) after Kilian (1975, pl. 72, 39-41)

a)  b) 

Figure I.6. Type IIa rings (A) AE 111 and (B) AE 459 with triangular cross section

I.2.2.1 Type IIa: triangular cross-section (6)

Triangular Type IIa rings include: AE 48, AE 459, AE 827, AE 936, AE 111, and AE 730. This type of rings have been recovered in the cemetery of Vitsa in Northern Greece and have been dated to 9th and early 8th century. This type has survived from the Late Helladic IIIC period down to the Protogeometric and Early Geometric as indicated by Protogeometric contexts of Vergina, Argos, Lefkandi, Tiryns, as well as Thessaly (Vokotopoulou 1986, pp. 313–314). Thus, a Protogeometric dating for those found in the Pheraean assemblage too is probable.

I.2.2.2 Type IIb: curved, plano-convex cross-section (4)

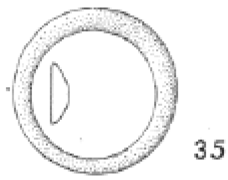
a)  b) 

Figure I.7. (A) Ring AE 680 with curved, plano-convex cross-section (Type IIb) and (B) drawing of similar ring after Kilian (1975, pl. 72, 35)

Unfortunately, no cut samples have been taken from any of the Type IIb rings (the only sample is severely corroded, see AE 14), and, thus, an overview of their cross-section is not at present available. Rings of this type include: AE 14, AE 631, AE 923, AE 432, and AE 680. Despite their small variation in the cross-section, a similar dating to the Protogeometric periods as for Type IIa is suggested.

I.2.3 Type III

As opposed to the aforementioned ring Types I and II, Type III is not formed from metal wire, but rather from thin metal sheet which has been folded and their endings are often open. Most often the sheet rings in this category have incised (Figure I.9) or embossed decoration (Figure I.10), while only ring AE 900 was found of plain metal sheet with no decoration (Figure I.8).

Figure I.8. (A) Type III ring AE 900 of plain sheet metal with no decoration and (B) drawing of similar ring after Kilian (1975, pl. 70, 53)

Figure I.9. (A) Type III ring AE 118 with incised decoration and (B) drawing of similar ring after Kilian (1975, pl. 70, 70)

Figure I.10. (A) Type III ring AE 799 with embossed decoration and (B) drawing of similar ring after Kilian (1975, pl. 71, 20)

Eight rings have been included in this group, namely AE 106, AE 118, AE 743, AE 776.2, AE 799, AE 806, AE 856, and AE 900. The contemporary character to the rest of the rings in the assemblage from the 9th to 7th and possibly the 6th centuries BC is argued here for this group rings on the basis of the circumstances of their recovery at the sanctuary of Enodia as no parallel finds have been so far identified by the author.

I.2.4 Type IV

Under Type IV, decorative rings with typically larger dimensions that would not allow them to be worn as fingerings are included. They have been further subdivided to Type IVa and IVb on the basis of the presence or not of any projections respectively. These rings have been also described as Macedonian bronzes and similar finds have been recovered from the burial contexts of Aeneia of the Archaic period (Vokotopoulou 1990).

I.2.4.1 Type IVa: simple thick-cross section rings (11)

Eleven rings have been characterised as Type IVa, namely AE 506, AE 760.1, AE 109, AE 245, AE 280, AE 483, AE 508, AE 540, AE 721, AE 776.1, and AE 94. Common characteristics for this group of rings are their rather variable but usually around 4 cm diameters, as well as their cross-section which is simple, i.e. round or ovoid, but thicker than the ones seen in Type Ia of around 0.5 cm (Figure I.11).

Figure I.11. Type IVa ring AE 508 with round/ovoid cross-section

a) 

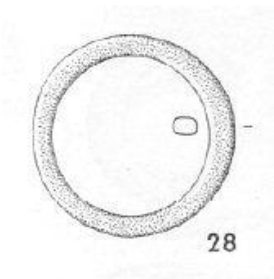
b) 

Figure I.12. (A) Type IVa ring AE 109 with ovoid cross-section and (B) drawing of similar ring after Kilian (1975, pl. 72, 28) (right)

Figure I.13.(A) Type IVb ring AE 95 with five projections and (B) drawing of similar ring after Kilian (1975, pl. 74, 10)

I.2.4.1 Type IVb: simple thick-cross section rings with projections (3)

The three rings in the subtype IVb, namely, AE 564, AE 773, and AE 95, all have in common the decorative projection on their outer surface (Figure I.13). Nonetheless, greater variation is seen in the actual number of these projections which are usually five, but rings with three or four projections have been also frequently found.

I.2.5 Type V

I.2.5.1 Type Va: spiral rings (4)

Four spiral rings with triangular or curved cross-section are included in the sample. In spite of the presence of the coils, they resemble Type IIa and IIb rings due to the shape of their cross-sections. Spiral rings included in this type are AE 107, AE 516, AE 624, AE 651, and AE 739 (Figure I.14).

a) b)

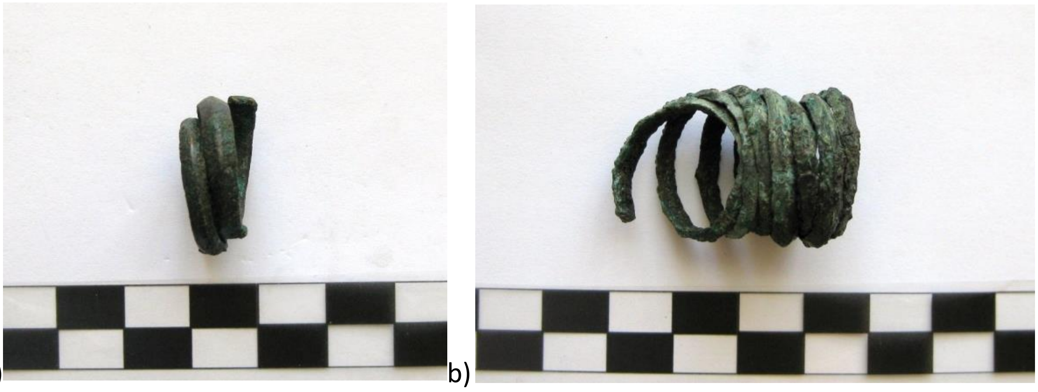


Figure I.14. Type Va spiral rings (A) AE 107 and (B) AE 651 with three and seven spirals respectively and triangular cross-section

I.2.5.2 Type Vb: spiral hair-attachment (1)

Only one spiral hair-attachment, namely AE 899, have been included in the sample, but this subtype was created due to its very characteristic shape (Figure I.15). Similar finds have been also recovered in Protogeometric cemetery of Vitsa (Vokotopoulou 1986, pp. 317–318, Tomb 113).

a) b)

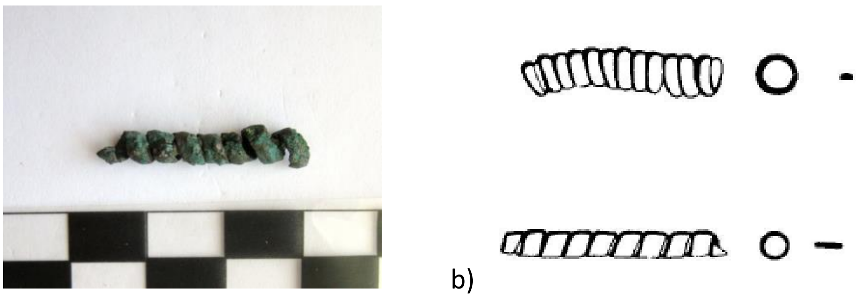


Figure I.15. (A) Type Vb syringe AE 899 and (B) drawings of similar syringes from Vitsa (after Vokotopoulou 1986, pl. 111, β-γ)

Table I.2. Summary table for the typological classification of the rings in the sample

Inv. No.	EPMA	pXRF	Description	Type	Alloy	Date
AE 798		VO191	ring	Ia	leaded bronze	*variable*
AE 261		VO175	ring	Ia	leaded bronze	*variable*
AE 765		VO211	ring	Ia	leaded bronze	*variable*
AE 26		VO187	ring	Ia	leaded bronze	*variable*
1310	57	VO227	ring	Ia	leaded bronze	*variable*
AE 507	60	VO260	ring	Ia	leaded bronze	*variable*
AE 34	64	VO262	ring	Ia	leaded bronze	*variable*
AE 796	43		ring	Ia	bronze	*variable*
AE 784.1	31	VO266	ring	Ia	bronze	*variable*
AE 597	56		ring	Ia	bronze	*variable*
AE 98	68	VO237	ring	Ia	bronze	*variable*
AE 97	70	VO234	ring	Ia	bronze	*variable*
AE 929	40	VO239	ring	Ia	bronze	*variable*
AE 246	19	VO241	ring	Ia	bronze	*variable*
AE 103	9	VO238	ring	Ia	bronze	*variable*
AE 810	11	VO254	ring	Ia	bronze	*variable*
M 2233.1	39		ring	Ia	bronze	*variable*
AE 633.1	33		ring	Ia	bronze	*variable*
AE 113	37	VO225A	ring	Ia	bronze	*variable*
AE 760.2	35		ring	Ia	bronze	*variable*
AE 37	77	VO235	ring	Ia	bronze	*variable*
AE 654	23		ring	Ia	bronze	*variable*
AE 733.1	12		ring	Ia	bronze	*variable*
AE 838	30	VO255	ring	Ib	bronze	PG-Archaic
AE 754	74		ring	Ib	bronze	PG-Archaic
AE 936		VO142	ring	IIa	copper	9th – early 8th c.
AE 730		VO188	ring	IIa	leaded bronze	9th – early 8th c.
AE 111		VO132	ring	IIa	bronze	9th – early 8th c.
AE 459	21	VO231	ring	IIa	bronze	9th – early 8th c.
AE 827	72	VO236	ring	IIa	bronze	9th – early 8th c.
AE 680		VO208	ring	IIb	leaded bronze	9th – early 8th c.
AE 631		VO153	ring	IIb	bronze	9th – early 8th c.
AE 432		VO193	ring	IIb	leaded bronze	9th – early 8th c.
AE 923		VO176	ring	IIb	bronze	9th – early 8th c.
AE 806		VO201	ring	III	bronze	(PG-Archaic?)
AE 776.2		VO213	ring	III	bronze	(PG-Archaic?)
AE 900		VO071	ring	III	copper	(PG-Archaic?)
AE 106		VO131	ring	III	bronze	(PG-Archaic?)
AE 118		VO205	ring	III	leaded bronze	(PG-Archaic?)
AE 743	32		ring	III	bronze	(PG-Archaic?)
AE 856	55		ring	III	bronze	(PG-Archaic?)
AE 799	62		ring	III	bronze	(PG-Archaic?)
AE 483		VO130	ring	IVa	bronze	PG-Archaic
AE 721		VO207	ring	IVa	leaded bronze	PG-Archaic
AE 508		VO206	ring	IVa	leaded bronze	PG-Archaic
AE 109		VO129	ring	IVa	leaded bronze	PG-Archaic

Inv. No.	EPMA	pXRF	Description	Type	Alloy	Date
AE 776.1		VO212	ring	IVa	copper	PG-Archaic
AE 94		VO134	ring	IVa	bronze	PG-Archaic
AE 280		VO210	ring	IVa	leaded bronze	PG-Archaic
AE 540		VO197	ring	IVa	bronze	PG-Archaic
AE 245		VO209	ring	IVa	leaded bronze	PG-Archaic
AE 506	42	VO258	ring	IVa	leaded bronze	PG-Archaic
AE 760.1	67	VO295	ring	IVa	bronze	PG-Archaic
AE 95		VO046	ring	IVb	leaded bronze	PG-Archaic
AE 773		VO199	ring	IVb	leaded bronze	PG-Archaic
AE 564	17	VO259	ring	IVb	bronze	PG-Archaic
AE 516		VO179	spiral	Va	bronze	PG-Archaic
AE 107	66	VO240	spiral	Va	bronze	PG-Archaic
AE 739.2	36	VO256	spiral	Va	bronze	PG-Archaic
AE 739.1	4		spiral	Va	bronze	PG-Archaic
AE 624	63	VO264	spiral	Va	bronze	PG-Archaic
AE 651	83		spiral	Va	bronze	PG-Archaic
AE 899	53	VO257	spiral	Vb	bronze	PG-Archaic

I.3 Pendants

Objects of decorative character that were intended to be hanged are classified as pendants. As a result, this is a widely varied group which includes several different artefact types. Overall, twenty four pendants have been included in the sample. The group of the bird pendants is best represented both in the assemblage and the analysed sample. Other kinds of pendants in the sample include these of different geometric shapes which often resemble beads with wide holes (biconical), as well as wheel disks and the double-axe one.

I.3.1 Bird pendants

Bird pendants at Pherae are most often seen in the assemblage and for that reason have also been well-represented in the sample. This group includes several different types of bird pendants. The most comprehensive study for this type of objects has been this of Voyatzis (1990) based on the investigation of the metal votive offerings at the sanctuary of Athena Alea at Tegea in Laconia. Following Voyatzis (1990, p. 150), the bird pendants in the sample can be identified as Corinthian (Figure I.16), Laconian, and Argive types which mostly date in the 8th and 7th centuries BC (see

Appendix III for more details of individual bird pendants). Furthermore, three hen pendants dated to around 700 BC (Kilian 1975, pl. 84) have been included in the sample (Figure I.17).

Figure I.16. Corinthian type bird pendants (A) M 2285 and (B) M 2286 in the sample

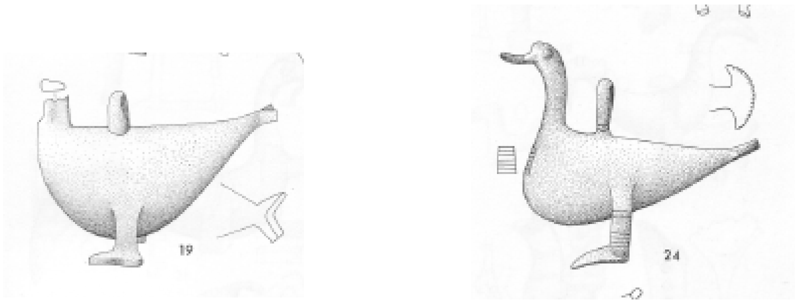


Figure I.17. Drawings of hen pendants from Thessaly (after Kilian 1983, pl. 84, nos. 19, 24)

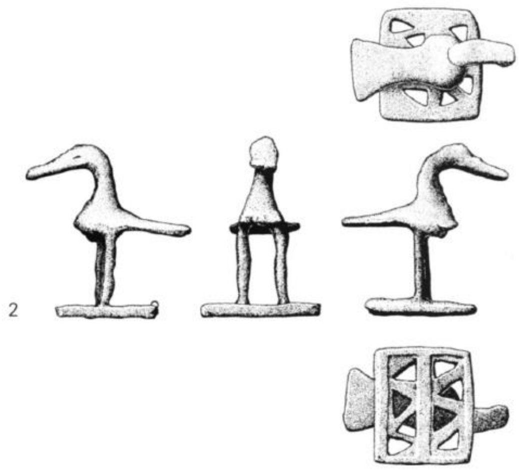


Figure I.18. Laconian type bird pendant recovered at the temple at Timpone della Motta in Calabria (after Kleinbrink et al. 2004, p. 47, fig. 1, no. 2)

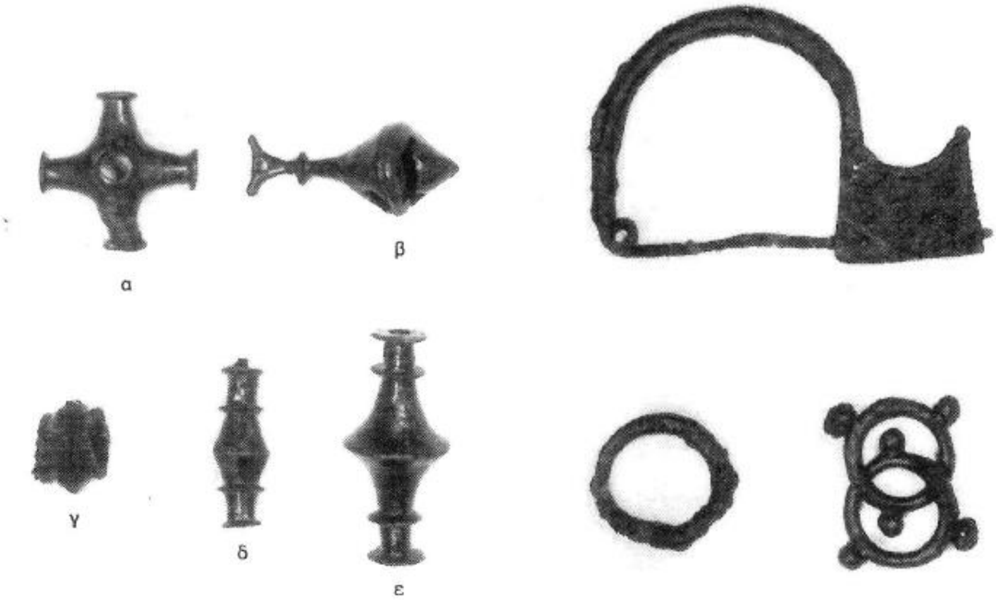


Figure I.19. Group of Macedonian bronzes from the tombs of Aeneia (after Vokotopoulou 1990, p. 63, Tomb VI)

Bird pendants were widely offered to many Early Iron Age sanctuaries all over Greece and the Aegean, but also elsewhere as indicated by Laconian type bird pendants found in Calabria as dedications to the temple at Timpone della Motta (Figure I.18) (Stoop 1972, Kleinbrink *et al.* 2004, p. 47) or in Locri Epizephyrioi, a Locrian colony established in 673 BC, also in Magna Grecia (Kilian-Dirlmeier 1979, pp. 164–167, Voyatzis 1990, p. 150, Coldstream 2003, p. 238), as well as in Austria, Silesia, and Bavaria (Bouzek 1967, in: Bouzek 1997, fig. 155). However, their popularity at Pherae should be also attributed to a certain extent to the proximity of the settlement to Lake Boebe which must have provided a good hunting environment of waterfowls. Bird pendants are on the whole dated from the early 8th century (Kilian-Dirlmeier 1979, Voyatzis 1990).

I.3.2 Biconical pendants

Biconical pendants resemble beads as they are perforated on their long sides. The five biconical pendants present in the sample, namely AE 20, AE 386, AE 533, AE 35, and AE 615, have been identified as Macedonian bronzes as similar finds have been recovered in the tombs of Aeneia (Figure I.19) and, in particular, dating to the Archaic period in the early 5th century by Vokotopoulou (1990, p. 63, Tomb VI, no. 7631; p. 65, Tomb IX, no. 8100).

Figure I.20. Biconical pendants/beads AE 20 (left), AE 533 (middle) and AE 35 (right) belonging to the group of Macedonian bronzes

Figure I.21. Wheel disc pendants M 1512.3 with two suspension holes (left) and M 1512.4 (right)

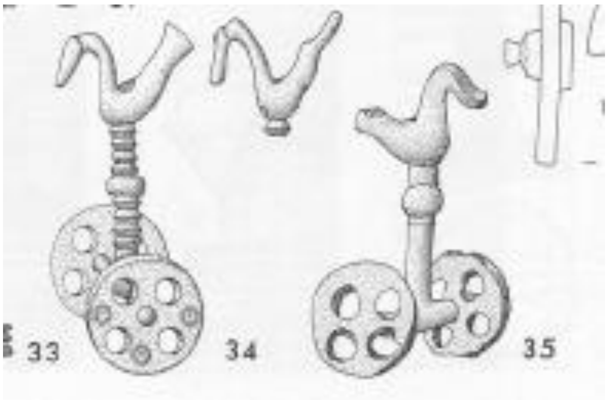


Figure I.22. Pendants of birds sitting on wheels from the sanctuary of Enodia in Pherae (after Kilian 1975, pl. 84, nos. 34-35)

I.3.3 Wheel disk pendants

Wheel disk pendants have been quite popular metal offerings in the Early Iron Age sanctuaries. They have been dedicated on their own right (Figure I.21), as well as they have been incorporated in certain bird pendant types (Figure I.22). Different types of wheel disks are present in the assemblage (for example compare pendants AE 268 and M 1518 in Figure I.23 with M 1512.3 and 4 in Figure I.22).

Figure I.23. Wheel pendant AE 268 with suspension hole and M 1518

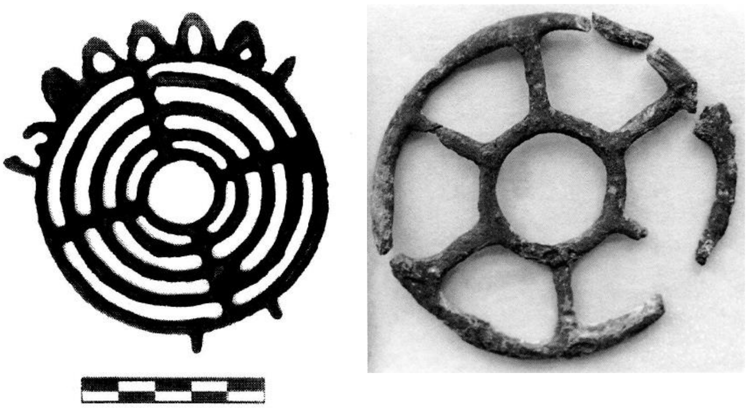


Figure I.24.Wheel disks from Agrosykia (Chrysostomou 2007, pl. III.25, no. 2) and Isthmia (Raubitschek 1998, pl. 9, no. 42) resembling wheel disk M 1518 from Pherae (Figure I.21)

Wheel pendant M 1518 finds parallels from other Geometric contexts of various characters such as female burials (Kilian-Dirlmeier 1979, pp. 28–29), the sanctuary at Isthmia (Raubitschek 1998 pl, 9, no. 42) and the settlement of Agrosykia (Chrysostomou 2007, p. 275, pl. IIIl.25, no. 2) (Figure I.24). Wheel pendants are often found in Early Iron Age cemeteries and burials, whereas such representations have been said to bear a certain symbolism related to the sun (Chrysostomou 2007, p. 230, after Andronikos 1969, p. 255, and Bouzek 1974, p. 138). Representations of metal wheels have been said to derived from the Balkan Urnfield cultures (Bouzek 1997, p. 110).

Finally, AE 427 and AE 514 are possibly not wheel pendants but could be a spectacle fibula decoration element (Blinkenberg 1926, p. 259, fig. 305) and a miniature shield respectively.

Figure I.25. Wheel pendant or spectacle fibula ornament AE 427 (left) and drawing of similar ornament after Blinkenberg (1926, p. 259, fig. 305)

Figure I.26. Disk pendant or miniature shield AE 752

I.3.4 Other pendants

In this category a few pendants with variable typologies have been classified, including the miniature double-axe pendant AE 749, the double spiral M 680.1 (

Figure I.27) and five biconical pendants/beads (AE 20, AE 35, AE 386, AE 533 and AE 615) (Figure I.30). The distribution of the miniature double-axe pendants which also held symbolic aspects have been found (Bouzek 1974, 1997, p. 106, fig. 103, Kilian-Dirlmeier 1979, pp. 244–258) (Figure I.28). From the Classical period the double-axe was a symbol of the Thessalian '*tageia'* (see also Chapter 1).

a)  b) 

Figure I.27. Pendants: (A) miniature double-axe AE 749, and (B) double spiral M 680.1

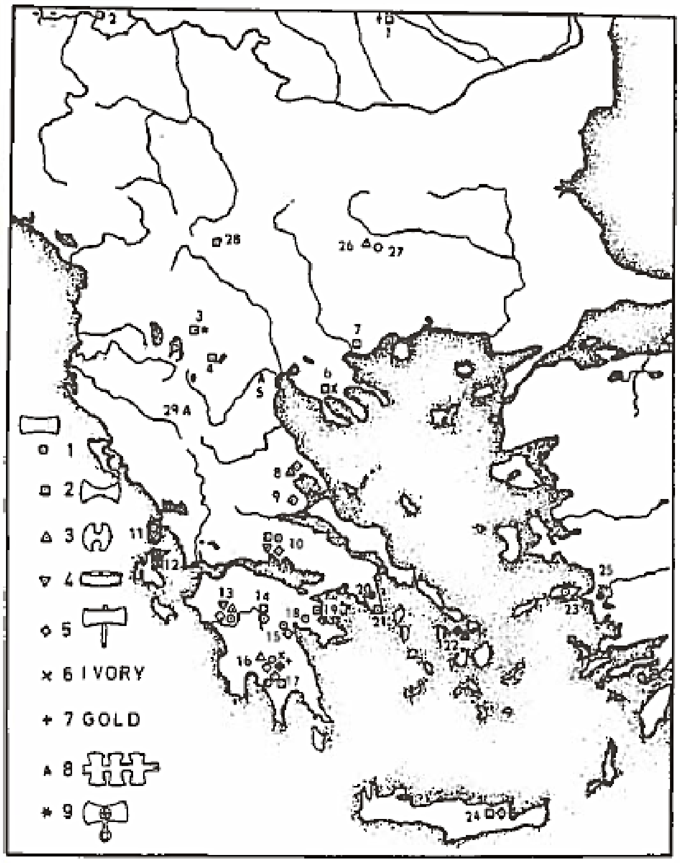


Figure I.28. Map of Greece showing the distribution of different miniature double-axe pendants (Bouzek 1997, fig. 103); Type 3 as seen in the map is the one included in the sample

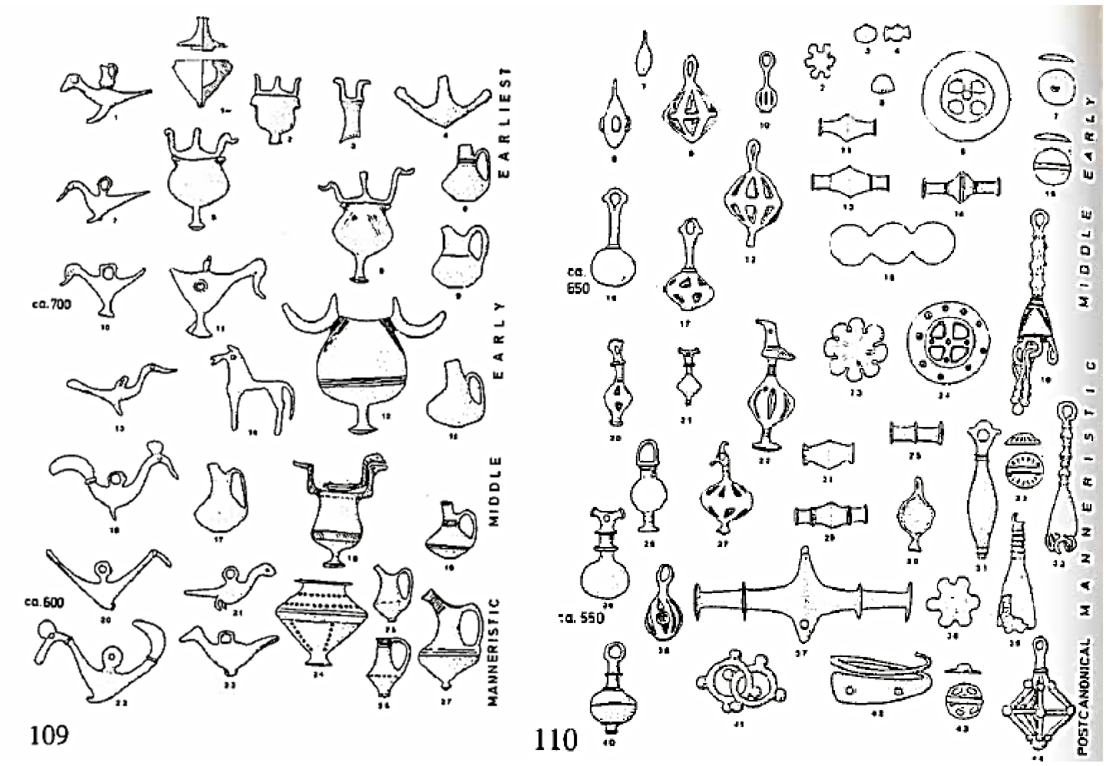


Figure I.29. Chronology and typology of the Macedonian bronzes after Bouzek (1997, figs. 109-110)

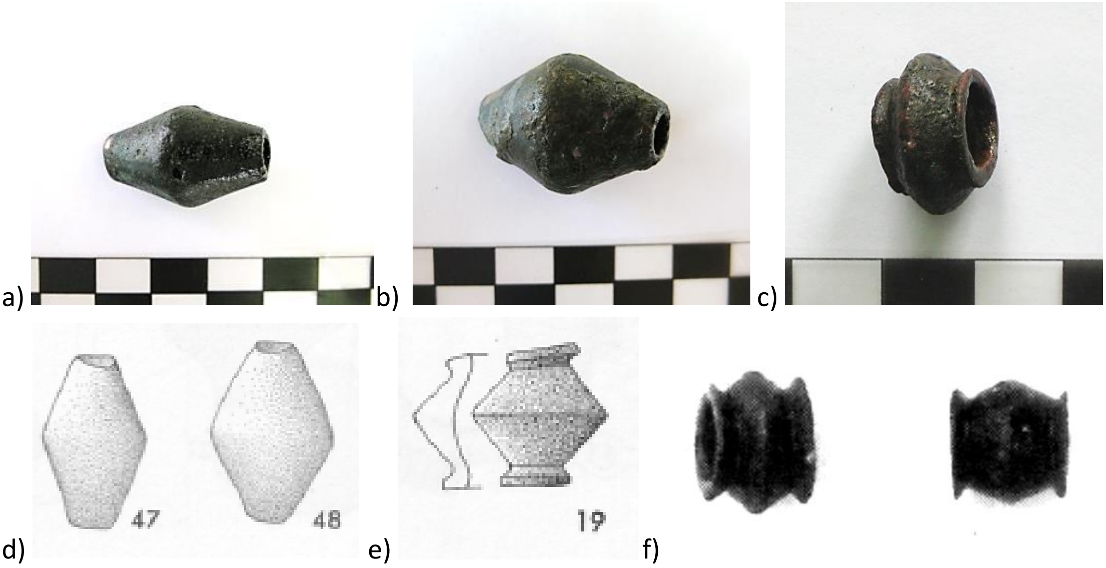


Figure I.30. Biconical pendants or beads (A) AE 20, (B) AE 386 and (C) 533 in the sample, (D, E) drawings of similar finds also from Pherae after Kilian (1975, pl. 75-76), and f) similar find after Vokotopoulou (1990, p. 63, Tomb VI, no. 7631)

The group of biconical pendants or beads falls under the Macedonian bronzes category and approximate dating is possible following Bouzek's typology, as well as parallels recovered in the Archaic Tombs of Aeneia and Olynthos. Thus, the biconical pendants/ beads AE 20 and AE 386 could be dated to 8th century BC in the Geometric period as they resemble the early type of Macedonian bronzes (Figure I.29), while the beads AE 35, AE 533, and AE 615 are dated somewhat later in the Archaic period and possibly as late at the early 5th century BC as indicated by finds in Olynthos (Type IIA) and the Tombs VI and IX in Aeneia (Vokotopoulou 1990, pp. 63, 65, Tombs VI & IX, nos. 7631, 8100).

I.4 Pins

Pins have a long tradition in Greek antiquity going back into the LBA, in contrast to the fibulae which are later introduced in Greece (Raubitschek 1998, p. 44). The origin of the Greek Late Bronze and Early Iron Age pins has raised a long standing debate amongst scholars which have different views on European connections for this artefact type. Presentation of the arguments of both sides is beyond the scope of this study; in short, though, it seems that the majority of scholars support a European origin and, in particular, a west Balkan or an Italian one, including Bouzek (1997, p. 117) and Jacobsthal (1956), whereas Kilian-Dirlmeier (1984) is amongst the few to reject such a proposal.

Seven pins have included in the sample; six for surface XRF analysis, namely AE 47, AE 86, AE 295, AE 537, and AE 538, and only pin 3673 for invasive. Pins are of different types and parallel finds dating to the Protogeometric and Geometric periods have been also recovered in the sanctuaries of Olympia, Isthmia and Kalapodi (for more details see Appendix III).

Appendix II. Quantitative data

II.1 EPMA data (normalised, wt%)

Sample	Descr.	Se	Zn	Ag	As	Fe	Cu	O	S	Cl	Sn	Bi	Co	Sb	Ni	Mn	Pb
M 1217.1	sheet	.010	n.d.	.000	.217	.147	90.991	.210	.017	.017	7.535	.002	.380	.022	.448	.002	.000
M 1217.2	fibula	.008	n.d.	.000	.052	.079	89.263	.237	.008	.006	10.226	.006	.001	.075	.009	.001	.029
AE 739.1	spiral	.013	n.d.	.003	.184	.120	91.012	.540	.056	.040	7.755	.005	.008	.089	.042	.002	.130
M 3367.1	fibula	.018	n.d.	.016	.151	.007	91.239	.034	.025	.017	7.882	.002	.001	.081	.030	.001	.496
AE 103	ring	.018	n.d.	.007	.172	.123	92.431	.052	.050	.002	6.926	.004	.003	.092	.029	.001	.091
M 3367.2	fibula	.006	n.d.	.001	.166	.025	90.778	.008	.041	.002	8.201	.004	.004	.094	.060	.003	.608
AE 810	ring	.008	n.d.	.000	.025	.175	93.697	.122	.046	.004	5.782	.001	.009	.015	.036	.002	.079
AE 733.1	ring	.011	n.d.	.000	.005	.069	88.336	.119	.020	.009	11.284	.003	.022	.033	.085	.002	.001
M 1739.3	fibula	.015	n.d.	.007	.182	.191	93.345	.068	.038	.007	5.908	.006	.004	.091	.027	.005	.104
M 1739.2	fibula	.013	n.d.	.000	.072	.023	88.817	.129	.014	.004	10.764	.009	.003	.091	.017	.002	.043
M 2277	pendant	.013	n.d.	.000	.321	.028	87.998	.174	.106	.006	11.038	.006	.006	.055	.028	.001	.218
AE 564	ring	.015	n.d.	.000	.011	.005	91.555	.377	.017	.055	5.959	.006	.002	.006	.011	.002	1.978
AE 246	ring	.004	n.d.	.003	.030	.309	94.013	.103	.022	.020	5.151	.007	.002	.029	.026	.003	.279
M 1314.1	fibula	.021	n.d.	.000	.058	.006	91.207	.098	.020	.030	6.777	.009	.010	.032	.070	.003	1.658
AE 459	ring	.012	n.d.	.017	.390	.513	87.916	.083	.121	.021	8.102	.015	.067	.256	.047	.002	2.438
AE 549	sheet	.094	n.d.	.000	.012	.470	92.666	.443	.006	.008	6.281	.006	.002	.004	.005	.002	.000
AE 654	ring	.043	n.d.	.000	.009	.035	84.863	.114	.004	.030	14.828	.006	.005	.044	.008	.001	.009
M 2276	pendant	.020	n.d.	.010	.046	.016	88.030	.116	.084	.009	11.229	.004	.004	.083	.035	.003	.312
M 1314.2	fibula	.006	n.d.	.000	.069	.018	89.703	.098	.042	.032	7.082	.018	.023	.031	.084	.003	2.793
M 3234	ring	.015	n.d.	.006	.135	.555	93.586	.004	.046	.011	5.400	.007	.001	.161	.039	.006	.028
AE 289	sheet	.021	n.d.	.109	.068	.001	99.218	.180	.004	.029	.030	.008	.002	.065	.019	.003	.243
M 1739.1	fibula	.035	n.d.	.007	.215	.027	87.253	.356	.022	.135	10.912	.013	.002	.102	.022	.004	.894
AE 606	sheet	.027	n.d.	.001	.071	.077	93.821	.001	.004	.029	5.841	.009	.017	.004	.029	.002	.067
AE 838	ring	.018	n.d.	.000	.018	.371	89.141	.575	.007	.038	9.773	.008	.002	.036	.014	.001	.000
AE 784.1	ring	.018	n.d.	.000	.143	.007	84.781	.190	.047	.060	11.554	.007	.009	.070	.111	.003	3.001
AE 743	ring	.027	n.d.	.000	.359	.047	87.539	.642	.020	.008	11.048	.008	.005	.180	.027	.002	.089
AE 633.1	ring	.112	n.d.	.006	.102	.105	92.986	.041	.010	.009	6.510	.005	.007	.037	.012	.003	.053
M 1815.2	fibula	.099	n.d.	.000	.024	.073	86.596	.431	.001	.015	12.680	.005	.002	.047	.017	.004	.004
AE 760.2	ring	.021	n.d.	.002	.639	.027	87.295	.101	.056	.028	11.554	.029	.010	.085	.124	.004	.024
AE 739.2	spiral	.020	n.d.	.000	.168	.113	90.929	.041	.076	.025	8.214	.008	.012	.115	.045	.001	.231
AE 113	ring	.007	n.d.	.011	.378	.055	93.623	.074	.016	.025	5.618	.008	.003	.116	.025	.002	.040
M 495.2	sheet	.013	n.d.	.002	.057	.231	94.665	.026	.033	.011	4.469	.010	.007	.008	.039	.003	.425
M 2233	fibula	.029	n.d.	.000	.352	.026	89.508	.001	.010	.019	9.835	.008	.003	.142	.012	.001	.055
AE 929	ring	.024	n.d.	.018	.160	1.134	92.773	.000	.035	.014	5.412	.005	.002	.068	.025	.003	.326

Sample	Descr.	Se	Zn	Ag	As	Fe	Cu	O	S	Cl	Sn	Bi	Co	Sb	Ni	Mn	Pb
M 1739.4	fibula	.019	n.d.	.013	.038	.014	87.393	.123	.028	.029	11.433	.013	.003	.078	.023	.004	.790
AE 506	ring	.018	n.d.	.000	.129	.014	79.049	.141	.028	.210	10.794	.032	.004	.074	.015	.003	9.489
AE 796	ring	.008	n.d.	.000	.032	.010	81.329	.901	.073	.290	13.887	.040	.032	.065	.073	.005	3.257
AE 578	sheet	.021	n.d.	.002	.181	.152	92.691	.133	.056	.021	6.630	.003	.015	.028	.023	.002	.040
AE 514	disk	.043	n.d.	.012	.103	.007	89.693	.011	.016	.036	9.824	.005	.004	.161	.024	.003	.059
AE 752	disk	.045	n.d.	.000	.013	.348	89.288	.336	.001	.019	9.884	.005	.003	.029	.022	.005	.002
1308	sheet	.004	n.d.	.042	.068	.000	99.396	.000	.008	.037	.006	.020	.003	.013	.023	.004	.375
3673	fibula	.016	n.d.	.000	.352	.139	90.346	.001	.013	.008	9.001	.010	.007	.055	.046	.003	.002
AE 899	spiral	.016	n.d.	.000	.170	.826	80.478	.000	.038	.000	17.661	.015	.013	.146	.060	.009	.568
AE 619	sheet	.000	n.d.	.025	.008	.019	89.834	.067	.005	.009	9.930	.002	.004	.047	.020	.005	.023
AE 856	ring	.000	n.d.	.000	.031	.201	87.815	.579	.000	.033	11.266	.008	.000	.014	.057	.000	.001
AE 597	ring	.018	n.d.	.001	.211	.085	90.357	.006	.060	.028	7.873	.011	.010	.118	.031	.003	1.188
1310	ring	.010	n.d.	.012	.065	.018	88.572	.005	.015	.042	2.458	.042	.001	.519	.027	.003	8.212
M 798	sheet	.014	n.d.	.038	.162	.025	70.095	2.303	.082	3.001	6.998	.051	.003	.092	.036	.003	17.096
1309	sheet	.018	n.d.	.000	.045	.133	88.930	.410	.008	.032	10.332	.003	.018	.045	.023	.004	.000
AE 507	ring	.011	n.d.	.000	.053	.007	79.463	.979	.087	.783	10.934	.043	.009	.196	.037	.001	7.396
AE 799	ring	.100	n.d.	.000	.007	.070	89.622	.192	.014	.025	9.830	.015	.029	.033	.058	.003	.000
AE 624	spiral	.011	n.d.	.000	.220	.151	91.148	.000	.048	.013	8.067	.008	.007	.110	.148	.005	.063
AE 34	ring	.008	n.d.	.005	.032	.009	89.271	.003	.012	.165	4.198	.016	.008	.003	.404	.004	5.863
AE 666	nail	.007	n.d.	.000	.019	.233	90.750	.000	.021	.029	8.827	.002	.035	.023	.049	.003	.004
AE 107	spiral	.017	n.d.	.015	.459	.209	91.053	.001	.091	.013	7.307	.010	.003	.280	.035	.005	.501
AE 760.1	ring	.012	n.d.	.008	.229	.004	93.413	.006	.049	.011	6.066	.012	.002	.055	.012	.002	.119
AE 98	ring	.018	n.d.	.007	.370	.051	92.530	.015	.045	.039	5.662	.004	.046	.164	.062	.003	.986
AE 97	ring	.015	n.d.	.001	.201	.023	90.558	.052	.043	.022	8.625	.008	.003	.088	.026	.006	.329
AE 827	ring	.016	n.d.	.004	.169	.023	90.615	.000	.056	.019	8.818	.002	.006	.069	.033	.004	.166
AE 249	sheet	.031	n.d.	.000	.103	.176	93.557	.238	.005	.038	5.747	.011	.036	.019	.034	.002	.001
AE 754	sheet	.008	n.d.	.000	.018	.081	88.348	2.151	.015	.128	9.157	.004	.030	.018	.038	.003	.000
M 1217.3	sheet	.008	n.d.	.001	.218	.168	90.381	.581	.014	.039	7.722	.007	.378	.027	.455	.000	.000
AE 480	sheet	.008	n.d.	.001	.109	.011	89.680	.024	.030	.004	9.907	.009	.017	.060	.020	.002	.117
AE 37	ring	.008	n.d.	.004	.147	.004	94.044	.000	.017	.009	5.545	.006	.003	.029	.158	.002	.024
Mμ 8100/ 2075	sheet	.013	n.d.	.000	.136	.096	89.702	.082	.014	.025	9.841	.008	.001	.051	.024	.002	.003
M 1217	sheet	.010	n.d.	.001	.193	.155	91.089	.312	.004	.047	7.311	.012	.390	.025	.450	.003	.000
M 1844	sheet	.014	n.d.	.000	.270	.302	92.543	.000	.008	.016	6.765	.006	.012	.031	.025	.002	.007
AE 66	sheet	.013	n.d.	.000	.129	.329	89.813	.033	.024	.014	9.355	.007	.003	.070	.024	.001	.185
AE 651	spiral	.077	n.d.	.000	.186	.833	90.152	.000	.009	.049	8.616	.009	.003	.039	.020	.001	.007
AE 744	sheet	.011	n.d.	.000	.216	.002	85.986	.111	.017	.033	12.172	.021	.194	.045	.405	.002	.786

II.2 pXRF data (normalised, wt%)

No.	Sample	Description	Cu	Sn	Pb	Zn	Fe	Ni	Sb	As
VO001	M 1666.2	fibula	84.919	12.055	1.828	.264	.553	.166	.081	.135
VO002	M 1666.3	fibula	85.914	11.969	.636	.257	.590	.299	.126	.210
VO003	M 1666.1	fibula	74.207	9.611	13.905	.310	.937	.224	.354	.451
VO004	M 1315.1	fibula	84.448	9.628	2.995	.467	1.521	.202	.190	.549
VO005	M 1315.2	fibula	86.531	9.336	2.744	.172	.754	.203	.104	.155
VO006	AE 275	fibula	87.733	10.343	.018	.347	.664	.285	.134	.476
VO008	M 884	bird pendant	85.602	12.071	.006	.251	1.620	.181	.108	.163
VO009	M 338	fibula	89.625	8.335	.147	.274	1.008	.199	.107	.308
VO010	AE 749/ BE 45731	doule-axe pendant	89.080	9.015	.365	.245	.502	.160	.266	.368
VO011	M 363	fibula	88.372	7.298	2.816	.277	.746	.264	.078	.148
VO012	M 1877	fibula	85.892	9.939	.000	.380	1.996	.214	.325	1.256
VO013	M 1794	fibula	84.306	11.938	1.098	.870	.868	.204	.368	.349
VO014	M 2222	fibula	79.782	14.628	3.991	.233	.503	.250	.257	.356
VO015	M 1512.4	wheel disk	87.003	10.823	.371	.327	.936	.216	.172	.153
VO016	M 1512.3	wheel disk	85.502	11.730	1.053	.314	.806	.189	.151	.256
VO017	M 2106	fibula	80.869	12.520	1.646	.778	3.608	.206	.104	.268
VO018	M 2228	fibula	88.696	8.700	1.570	.269	.222	.132	.095	.316
VO019	M 2116	fibula	85.729	9.027	2.758	.499	1.509	.164	.132	.182
VO020	M 2125	fibula	95.303	2.804	.000	.547	.392	.191	.232	.531
VO022	M 2265	fibula	93.457	4.719	.750	.326	.104	.215	.152	.277
VO023	M 2109	fibula	85.747	10.403	1.185	.587	1.191	.251	.266	.371
VO024	M 3298.1	fibula	89.602	7.561	.968	.457	.648	.233	.209	.324
VO025	M 3298.2	fibula	86.053	11.463	.685	.255	.956	.199	.129	.262
VO026	M 1585.2	fibula	84.718	7.812	6.107	.299	.482	.172	.086	.325
VO027	M 776.1	fibula	92.988	3.225	.152	.355	2.491	.265	.168	.357
VO028	M 776.2	fibula	98.704	.259	.000	.360	.163	.161	.102	.253
VO029	M 776.3	fibula	94.811	2.605	.000	.317	1.707	.239	.088	.233
VO030	M 3268	fibula	83.909	10.401	.980	.402	2.925	.171	.487	.727
VO031	M 339	fibula	86.510	11.011	1.149	.250	.637	.182	.093	.171
VO032	M 282	fibula	82.464	6.145	10.468	.239	.302	.164	.066	.155
VO033	M 775	fibula	94.797	2.512	.011	.232	2.006	.163	.071	.212
VO034	M 214.2	fibula	91.064	7.267	.670	.297	.161	.224	.136	.184
VO035	M 262	fibula	87.433	10.690	.353	.302	.734	.115	.100	.275
VO036	M 1812.3	fibula	80.824	12.855	.429	.258	4.699	.261	.086	.591
VO037	M 1812.1	fibula	87.610	7.732	2.113	.308	1.483	.241	.179	.337
VO038	M 1812.2	fibula	87.911	9.309	.858	.270	.745	.212	.291	.405

No.	Sample	Description	Cu	Sn	Pb	Zn	Fe	Ni	Sb	As
VO039	M 2104	fibula	88.833	6.338	2.876	.664	.638	.245	.167	.241
VO040	M 2111	fibula	88.769	8.024	1.735	.435	.556	.186	.117	.179
VO041	AE 726	fibula	88.149	8.364	.630	.272	2.177	.110	.086	.212
VO042	AE 538	pin	79.645	12.420	6.756	.282	.482	.160	.090	.167
VO043	M 1518	wheel disk	90.070	8.013	.741	.269	.270	.221	.133	.286
VO044	M 1433	pin	89.913	8.483	.514	.289	.237	.184	.083	.300
VO045	AE 148	nail	81.464	7.974	7.494	.248	2.424	.153	.088	.157
VO046	AE 95	ring	80.299	4.522	13.698	.635	.316	.226	.099	.207
VO047	M 2097	fibula	89.970	8.516	.041	.377	.595	.145	.149	.208
VO048	M 2292	undiagnosed	71.234	4.645	21.783	.617	1.198	.224	.132	.169
VO049	M 2099	fibula	86.297	11.503	.105	.422	1.023	.166	.093	.393
VO050A	M 1843.1	fibula	88.447	.468	.802	9.277	.581	.119	.073	.236
VO050B	M 1843.2	fibula	98.863	.106	.000	.348	.146	.225	.079	.234
VO051A	M 2117.1	fibula	90.500	7.287	.000	.461	1.207	.135	.137	.273
VO051B	M 2117.2	fibula	94.682	3.697	.000	.405	.677	.180	.108	.254
VO052	M 1863.1	bird pendant	81.048	11.934	5.061	.290	1.135	.195	.154	.184
VO053	M 2279	bird pendant	89.509	8.280	.000	.743	1.098	.104	.092	.175
VO054	M 2285	bird pendant	80.413	10.510	7.264	.384	1.009	.081	.121	.220
VO055	M 2286	bird pendant	86.780	10.721	.213	.879	.822	.147	.114	.325
VO056	M 786	bird pendant	83.181	11.856	1.786	.278	2.216	.278	.187	.220
VO057	M 885	bird pendant	88.436	9.787	.000	.274	.491	.119	.107	.787
VO058	M 2284	bird pendant	85.413	11.975	.897	.982	.351	.156	.086	.143
VO059	M 1358.2	undiagnosed	87.019	8.636	2.630	.310	.857	.181	.106	.263
VO060	M 1358.3	horse figurine	86.611	7.921	2.328	.354	2.325	.210	.094	.161
VO061	M 1358.1	bird pendant	80.513	13.568	3.170	.282	1.580	.152	.313	.424
VO062	M 2230	fibula	90.116	5.194	3.265	.559	.434	.157	.082	.197
VO063	M 1413	fibula	88.524	9.394	.867	.279	.309	.145	.155	.328
VO064	M 2229	fibula	85.605	10.814	2.483	.303	.239	.199	.076	.283
VO065	M 2234	fibula	84.635	7.244	7.045	.402	.254	.166	.069	.186
VO066	M 2262	fibula	88.896	4.348	5.046	.372	.929	.145	.079	.188
VO067	M 757	fibula	90.909	6.099	2.132	.261	.192	.156	.070	.183
VO068	AE 441	sheet	85.206	7.624	5.090	.672	1.032	.139	.088	.151
VO069	AE 20	biconical pendant	80.939	13.282	3.264	.296	.746	.182	.711	.581
VO070	AE 484	undiagnosed	85.800	9.518	1.934	.277	1.919	.175	.088	.289
VO071	AE 900	ring	97.426	.529	.000	.294	1.319	.118	.078	.237
VO072	M 2226	fibula	85.201	8.570	3.856	1.056	.630	.229	.094	.365

No.	Sample	Description	Cu	Sn	Pb	Zn	Fe	Ni	Sb	As
VO073	M 1909	fibula	90.353	8.018	.596	.243	.316	.173	.112	.192
VO074	M 8084/2055	fibula	90.954	7.947	.000	.261	.374	.163	.078	.225
VO075	M 1731.2	fibula	88.539	7.097	3.389	.244	.299	.165	.088	.179
VO076	M 2114	fibula	86.192	7.461	5.093	.640	.244	.113	.073	.185
VO077	M 1225	fibula	85.946	10.919	1.196	.674	.704	.210	.119	.233
VO078	M 2096	fibula	82.564	14.254	1.169	.362	.744	.232	.280	.398
VO079	M 2136	fibula	90.240	8.451	.000	.238	.253	.198	.097	.525
VO080	M 2237	fibula	92.772	5.915	.246	.275	.248	.180	.169	.197
VO081	AE 310	bird pendant	84.353	13.937	.288	.261	.343	.118	.256	.446
VO082	AE 290	undiagnosed	89.287	9.525	.000	.285	.472	.134	.125	.175
VO083A	M 2233.2	fibula	85.690	9.601	3.434	.313	.346	.262	.098	.258
VO084	M 1928	fibula	86.863	10.221	1.071	.303	.783	.214	.209	.338
VO085	M 1646	fibula	92.529	5.058	.450	.241	1.243	.120	.162	.198
VO086	M 3362	fibula	89.408	6.128	2.921	.260	.636	.255	.090	.304
VO087	M 2105	fibula	92.433	2.969	2.802	.346	.860	.146	.167	.278
VO088	M 538	fibula	85.700	10.724	1.115	.297	1.613	.229	.087	.236
VO089	M 1661.4	fibula	86.202	10.994	1.880	.210	.363	.115	.075	.162
VO090	M 1661.7	fibula	88.318	7.743	2.436	.301	.798	.155	.075	.175
VO091	M 1661.6	fibula	83.549	9.141	6.357	.268	.393	.091	.076	.127
VO092	M 1661.1	fibula	88.245	6.594	4.328	.301	.170	.117	.079	.167
VO093	M 1661.3	fibula	85.158	6.555	4.746	.211	2.906	.124	.101	.201
VO094	M 1661.5	fibula	89.459	4.445	4.699	.287	.408	.156	.212	.336
VO095	M 1661.2	fibula	88.272	8.871	1.699	.241	.501	.129	.092	.197
VO096	M 1815.4	fibula	87.263	10.706	.073	.366	1.042	.141	.097	.315
VO097	M 1815.3	fibula	90.221	7.902	.713	.325	.287	.169	.079	.308
VO098	M 1815.1	fibula	88.572	6.311	3.520	.260	.857	.191	.087	.205
VO099	M 226.2	fibula	87.142	11.069	.701	.241	.500	.119	.082	.146
VO100	M 226.1	fibula	69.512	9.090	20.114	.253	.457	.133	.148	.296
VO101	AE 120	nail	77.105	7.066	13.973	.291	.887	.223	.192	.265
VO102	M 1735.4	fibula	87.605	7.134	3.495	.872	.361	.213	.131	.191
VO103	M 1735.1	fibula	87.550	7.610	3.638	.297	.466	.172	.088	.182
VO104	M 1735.2	fibula	97.024	1.280	.003	.298	.637	.173	.164	.423
VO105	M 1735.3	fibula	87.517	9.417	1.693	.280	.591	.269	.091	.144
VO106	M 1734.1	fibula	77.615	13.813	7.204	.261	.671	.178	.108	.152
VO107	M 1734.3	fibula	73.898	11.229	13.097	.271	.749	.376	.081	.299
VO108	M 1734.2	fibula	90.009	5.959	2.961	.312	.203	.208	.084	.267
VO109	M 1734.4	fibula	85.545	9.441	3.693	.298	.454	.193	.112	.267
VO110	M 1734.5	fibula	82.067	10.935	5.786	.270	.505	.173	.098	.166

No.	Sample	Description	Cu	Sn	Pb	Zn	Fe	Ni	Sb	As
VO111	M 1345.1	fibula	91.939	6.814	.000	.308	.336	.138	.113	.353
VO112	M 1345.2	fibula	90.932	4.977	2.482	.229	.445	.166	.214	.556
VO113	M 1345.3	fibula	96.887	.277	.060	1.088	.798	.555	.120	.216
VO115A	M 2232.2	fibula	84.662	9.418	3.932	.510	.890	.148	.154	.287
VO117	M 1731.4	fibula	78.795	14.592	5.471	.263	.334	.212	.105	.231
VO117A	M 1731.4	fibula	78.117	14.778	6.047	.236	.386	.202	.089	.147
VO118	M 1731.3	fibula	83.809	8.554	6.660	.218	.365	.165	.085	.145
VO119	M 1731.1	fibula	87.261	8.495	2.926	.284	.597	.191	.083	.165
VO120	M 745.1	fibula	86.984	11.193	.000	.314	.260	.227	.244	.781
VO121	M 745.3	fibula	85.576	9.196	4.129	.254	.439	.124	.124	.158
VO122	M 745.5	fibula	82.086	11.232	5.816	.279	.264	.082	.082	.162
VO123	M 745.4	fibula	83.633	8.776	5.974	.346	.845	.183	.099	.148
VO124	M 745.2	fibula	88.836	6.231	4.015	.290	.190	.193	.072	.176
VO125	M 2293	bird pendant	84.890	11.401	2.170	.569	.446	.113	.153	.261
VO126	AE 928	arm band	84.380	12.954	.769	.232	1.307	.132	.090	.137
VO127	M 926.1	bird pendant	73.982	10.707	14.028	.248	.537	.143	.110	.246
VO128	M 926.2	bird pendant	87.001	11.295	.322	.276	.610	.142	.115	.239
VO129	AE 109	ring	83.927	10.223	4.625	.314	.438	.215	.078	.183
VO130	AE 483	ring	87.450	8.258	.000	1.407	2.268	.229	.185	.204
VO131	AE 106	ring	86.072	10.877	.970	.274	1.297	.211	.128	.175
VO132	AE 111	ring	87.492	11.154	.421	.245	.280	.176	.089	.146
VO133	AE 47	pin	91.111	6.808	.031	.335	.799	.189	.384	.345
VO134	AE 94	ring	87.838	10.127	.777	.297	.423	.158	.088	.293
VO135	AE 86/BE 45749	pin	89.414	3.237	.000	6.412	.402	.201	.159	.177
VO136	M 3224.2	arm band	86.953	11.428	.554	.312	.342	.183	.081	.150
VO137	M 3224.4	arm band	88.594	9.822	.180	.254	.577	.321	.100	.155
VO138	M 3224.1	arm band	86.988	11.624	.128	.272	.404	.174	.107	.303
VO139	M 3224.3	arm band	88.634	9.707	.497	.274	.443	.205	.082	.160
VO140	M 3224.5	arm band	84.542	12.430	.917	.251	1.427	.208	.098	.129
VO141	AE 537	pin	89.676	8.715	.544	.262	.442	.112	.088	.164
VO142	AE 936	ring	93.484	2.999	.592	.319	.235	.143	1.000	1.228
VO143	M 1801.4	arm band	88.378	9.870	.750	.233	.252	.181	.106	.233
VO144	M 1801.3	arm band	91.338	7.125	.386	.280	.407	.162	.079	.224
VO145	M 1801.2	arm band	88.685	10.259	.020	.296	.238	.151	.079	.274
VO146	M 1801.1	arm band	88.164	10.487	.151	.334	.206	.180	.087	.394
VO147	M 3229.3	arm band	91.115	8.055	.000	.286	.189	.125	.077	.155
VO148	M 3229.2	arm band	88.569	9.356	.000	.277	1.013	.231	.170	.386

No.	Sample	Description	Cu	Sn	Pb	Zn	Fe	Ni	Sb	As
VO149	M 3229.1	arm band	90.696	5.220	.732	.320	2.516	.186	.076	.257
VO150	M 3229.4	arm band	88.633	10.367	.205	.269	.162	.161	.070	.134
VO151	AE 661	fibula	90.061	7.000	.668	.243	.838	.251	.112	.831
VO152	AE 417	vessel handle	86.021	12.676	.000	.273	.465	.140	.082	.344
VO153	AE 631	ring	83.212	12.917	2.553	.263	.595	.200	.090	.173
VO154	M 4418.2.2	metal band	85.092	13.201	.622	.278	.449	.069	.090	.202
VO155	M 4418.5.2	tweezers	88.944	5.977	.000	.263	1.043	.131	1.300	2.345
VO156	M 4418.2.3	metal band	87.722	10.370	.000	.260	1.283	.083	.105	.180
VO157	M 4418.7.16	arm band	88.250	9.625	1.162	.250	.242	.204	.077	.191
VO158	M 4418.5.1	tweezers	87.907	9.614	.713	.285	.986	.138	.099	.260
VO159	M 4418.7.13	vessel handle	82.879	15.903	.000	.276	.616	.125	.082	.122
VO160	M 680.1	undiagnosed	91.694	5.088	.173	.302	1.836	.209	.228	.472
VO161	AE 153	decorative ornament	85.452	7.718	5.729	.267	.456	.140	.077	.164
VO162	AE 811	fibula	83.704	11.389	3.198	.256	.435	.167	.134	.719
VO163	AE 386	biconical pendant	72.034	11.444	10.722	.268	5.189	.152	.074	.117
VO174	AE 268	wheel disk	88.897	8.249	1.232	.367	.573	.128	.263	.293
VO175	AE 261	ring	73.915	12.949	9.839	.271	2.289	.162	.251	.327
VO176	AE 923	ring	84.631	13.104	1.095	.248	.489	.132	.096	.207
VO177	AE 720	fibula	83.294	14.774	.771	.247	.399	.149	.109	.260
VO178	AE 626	fibula	88.691	10.026	.025	.288	.496	.143	.131	.202
VO179	AE 516	spiral ring	86.680	11.542	.360	.310	.445	.166	.181	.318
VO180	AE 843	fibula	84.703	12.312	1.400	.255	.727	.141	.105	.361
VO181	AE 295	pin	66.468	9.179	22.173	.609	1.272	.071	.108	.120
VO182	AE 585	fibula	92.193	3.542	.766	.277	1.586	.294	.178	1.165
VO183	AE 294	decorative ornament	82.347	6.552	9.112	.273	1.134	.188	.227	.168
VO184	AE 418	decorative ornament	82.603	9.159	3.695	.275	3.718	.207	.151	.193
VO185	AE 533	biconical pendant	88.745	9.957	.095	.238	.440	.121	.106	.301
VO186	AE 279	sheet	83.887	7.318	7.628	.258	.409	.230	.118	.155
VO187	AE 26	ring	65.019	10.774	22.327	.188	.538	.185	.289	.684
VO188	AE 730	ring	77.926	6.301	14.624	.246	.256	.211	.184	.254
VO189	AE 473	decorative ornament	84.817	12.632	.795	.332	.619	.430	.231	.146
VO190	AE 650	fibula	82.864	11.840	3.047	.265	1.438	.152	.129	.267
VO191	AE 798	ring	84.871	5.008	6.955	.301	1.307	.299	.573	.688
VO192	AE 487	undiagnosed	98.412	.311	.000	.308	.337	.229	.103	.302
VO193	AE 432	ring	80.876	12.505	5.098	.259	.640	.152	.214	.259

No.	Sample	Description	Cu	Sn	Pb	Zn	Fe	Ni	Sb	As
VO194	AE 203	nail	86.672	6.605	5.616	.271	.330	.211	.143	.153
VO195	AE 738	fibula	86.659	12.072	.122	.245	.253	.152	.100	.399
VO196	AE 465	fibula	85.579	8.894	3.636	.313	.515	.219	.261	.586
VO197	AE 540	ring	90.041	7.630	.813	.283	.779	.166	.099	.191
VO198	AE 35	biconical pendant	91.388	6.576	.582	.317	.572	.230	.116	.221
VO199	AE 773	ring	86.104	4.568	8.501	.194	.200	.153	.085	.197
VO200	AE 427	wheel disk	85.723	10.302	.334	1.114	1.844	.228	.207	.250
VO201	AE 806	ring	88.052	9.558	.045	.351	1.076	.335	.167	.417
VO202	AE 577	decorative ornament	84.969	8.243	3.790	.243	2.292	.181	.120	.164
VO203A	AE 502	undiagnosed	78.159	6.835	12.590	.250	1.598	.208	.114	.248
VO203B	AE 502	undiagnosed	81.339	16.527	.000	.288	.993	.209	.085	.558
VO204	AE 615	biconical pendant	82.096	14.666	2.074	.226	.542	.147	.099	.152
VO205	AE 118	ring	88.029	6.148	4.298	.247	.548	.313	.146	.273
VO206	AE 508	ring	80.706	7.001	10.017	.339	.801	.215	.169	.752
VO207	AE 721	ring	80.464	12.279	4.049	1.176	1.341	.271	.252	.171
VO208	AE 680	ring	84.350	6.376	7.652	.317	.563	.197	.199	.348
VO209	AE 245	ring	76.605	10.556	11.262	.244	.686	.235	.236	.179
VO210	AE 280	ring	80.360	11.581	6.248	.292	.874	.241	.201	.206
VO211	AE 765	ring	64.937	6.046	26.539	.239	.844	.208	.397	.793
VO212	AE 776.1	ring	96.317	1.540	.000	.303	.854	.174	.235	.579
VO213	AE 776.2	ring	88.125	10.425	.101	.335	.599	.195	.087	.134
VO214	AE 311	sheet	84.882	13.288	.247	.265	.878	.217	.095	.130
VO215	AE 614	undiagnosed	86.963	11.091	.000	.332	.507	.178	.221	.709
VO216	AE 116	undiagnosed	96.983	.636	.000	.322	.742	.171	.092	1.056
VO217	AE 740	fibula	92.712	5.588	.000	.330	.407	.315	.117	.532
VO218	AE 871	fibula	93.349	2.479	1.391	.320	1.910	.197	.168	.187
VO219	AE 451	bead	72.914	20.324	4.666	.302	.692	.264	.192	.650
VO21A	M 2122.1	fibula	87.048	9.763	1.747	.340	.609	.157	.110	.226
VO21B	M 2122.2	fibula	83.608	7.068	4.871	2.630	.961	.261	.414	.187
VO248	M 8100/2075	sheet	85.479	12.857	.000	.593	.501	.183	.298	.238

Appendix III. Description of the sample

Below the objects included in the sample are presented individually according to artefact type rather than their analytical methodology, i.e. pXRF or EPMA, chemical composition, or the alphabetical order of their inventory numbers. It is argued that such grouping will reveal further the typological connections of the artefacts as also discussed in Appendix I. For each sample, a photograph and a photomicrograph (in plain polarised – PPL, unless otherwise indicated – XPL), in the case of the cut samples, measurements for their dimensions and weight, along with a concise metallographic description and information on their bulk composition are given. In Table III.1 a list of the abbreviations used in the catalogues below is given. Finally, all measurements are presented in grams (gr) in the case of weight or in centimetres (cm) for all other dimensions, and all photomicrographs are in plain polarised mode (PPL), unless otherwise indicated. Estimations on the corrosion effects on as seen from the objects' surface is also given with a scale from A (objects that have undergone conservation treatment), B (only thin layer of surface patina), C (surface is rather disrupted often with evidence of bronze disease) to D (surface severely disrupted often with no metal preserved).

Table III.1. List of abbreviations used in Appendix III

Abbreviation	
D	diameter (exterior)
H	height
Im.W.	image width
L	length
Magn.	magnification
max	maximum
min	minimum
PPL	plain polarised filter
Th	thickness
Wdt	width
Wgt	weight
XPL	cross polarised filter

III.1 Invasive sampling (EPMA, OM)

1308

Macroscopic characterisation

description	metal sheet
EPMA no.	51
metal	bronze
Wgt	1.32 gr
Th (min)	0.05 cm
Th (max)	0.09 cm
L	2.25 cm
Wdt	1.5 cm
Corrosion	B

Fragmented, thin metal sheet.

Metallography

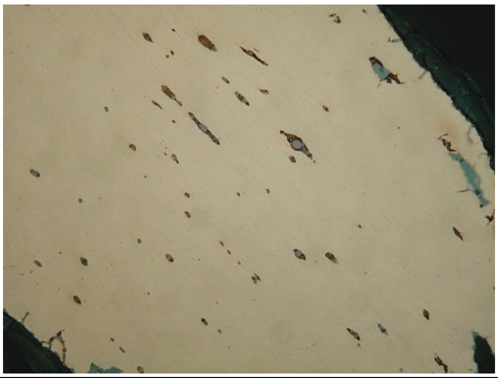
The sample was cut from one of the corners of the metal sheet fragment and its cross-section was embedded in the resin block.

The metal revealed signs of mechanical stress such as the elongated, thin lead and sulphide inclusions. Few metallic grains were visible close to the sample's surface and chemical etching would be needed for a more detailed examination of the metal's microstructure.

Corrosion: Limited corrosion has affected the substrate of the sample, while the metal is rather intact. A thin patina layer has formed on its surface with no growth corrosion layers.

Magn: 50x Im.W.: 3.5 mm

Magn: 500x Im.W.: 350 µm



1309

Macroscopic characterisation

description	metal sheet
EPMA no.	59
metal	bronze
Wgt	1.11 gr
Th (min)	0.12 cm
Th (max)	0.40 cm
L	1.90 cm
Wdt	1.35 cm
Corrosion	B

Fragment of folded metal sheet.

Metallography

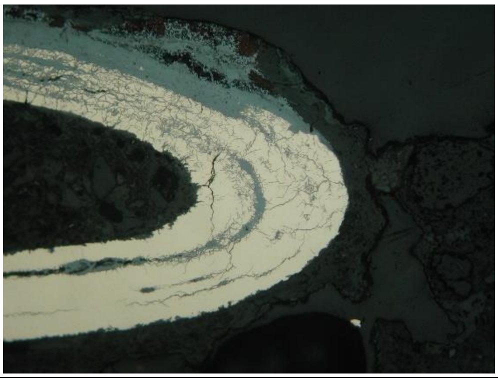
The sample was cut from one of the metal sheet's fragmented ends.

The embedded cross section revealed the form in which the thin sheet has been folded. The metal revealed a microstructure of small, angular metallic grains with strain lines and annealing twins. Thin cracks in the metal have formed in the places where extra mechanical stress was applied such as in the folded parts.

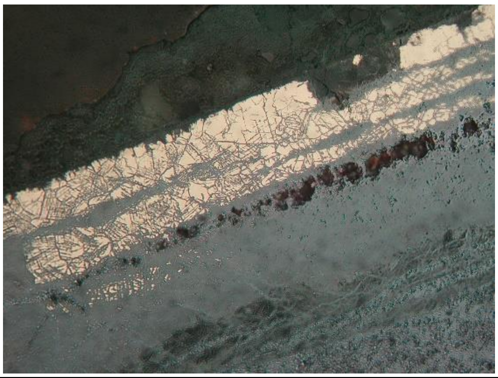
Corrosion: Destructive corrosion has replaced only a small part of the metal sheet. Patina covers its surface, and in places thick growth corrosion products have been formed.

Magn: 50x Im.W.: 3.5 mm

Magn: 200x Im.W.: 0.9 mm



Magn: 500x Im.W.: 350 μm



1310

Macroscopic characterisation

description	ring
EPMA no.	57
metal	leaded bronze
Wgt	0.87 gr
Th (min)	0.18 cm
Th (max)	0.20 cm
Wdt	0.50 cm
L	2.5 cm
Corrosion	B

Simple, round cross-section wire ring (fragmented) (Type Ia).

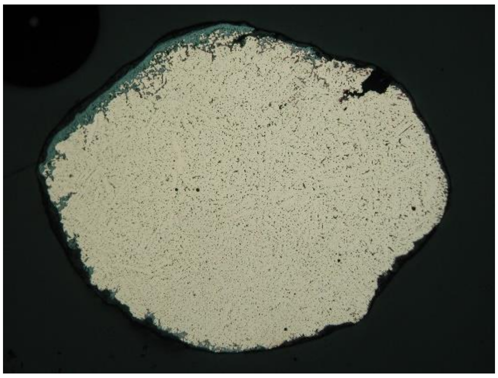
Metallography

The sample was cut from one of the fragmented ends of the ring's preserved length. The cross-section of the sample was embedded in the resin block.

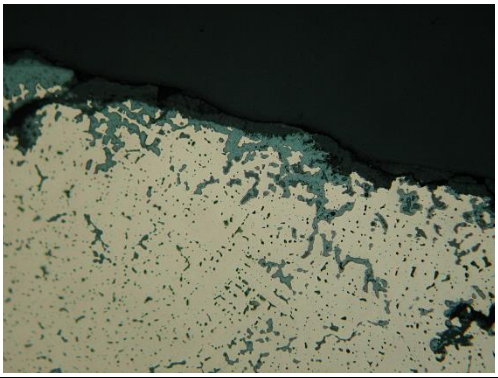
The cross section has an uneven, ovoid shape. The metal micromorphology revealed an as cast structure with dendrites throughout the sample. A plethora of lead prills precipitating in between dendrite boundaries were also found. Dendrites in the middle of the metal wire show signs of slower cooling than those closer to the surface.

Corrosion: Limited corrosion has affected the sample in which a substantial metal core is preserved. A thin layer of patina covers the sample's surface.

Magn: 50x Im.W.: 3.5 mm



Magn: 500x Im.W.: 350 μm



Magn: 200x Im.W.: 0.9 mm

3673

Macroscopic characterisation

description	pin
EPMA no.	52
metal	bronze
Th (min)	0.20 cm
Th (max)	0.40 cm
L	6.7 cm
Corrosion	B

Small pin with round cross-section and small, decorative globules at the top

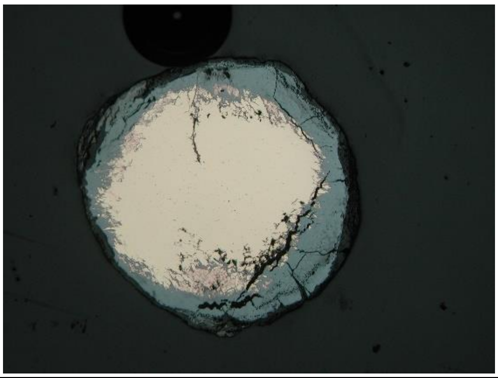
Metallography

The sample was cut from the pins end and its cross-section was embedded in the resin block.

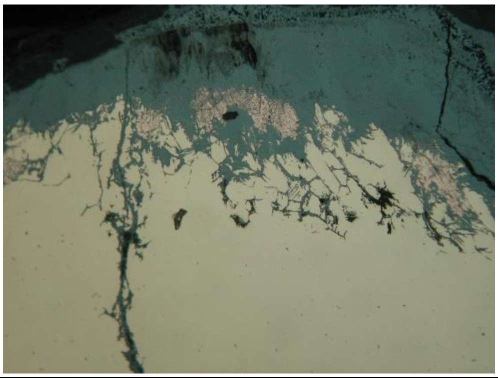
The preserved metal core revealed signs of mechanical stress such as polygonal, angular metallic grains often forming triple points (equiaxed structures), and with strain lines and annealing twins. Small sulphide and lead inclusions have been found.

Corrosion: a layer of destructive corrosion has affected the metal's substrate while its original surface is not preserved. Inter- and intra-granular corrosion has highlighted the microstructure.

Magn: 50x Im.W.: 3.5 mm



Magn: 200x Im.W.: 0.9 mm



AE 14

Macroscopic characterisation

description	ring
EPMA no.	(not included)
metal	corroded
Wgt	0.43 gr
Th (max)	0.25 cm
Wdt	0.45 cm
L	1.4 cm
Corrosion	D

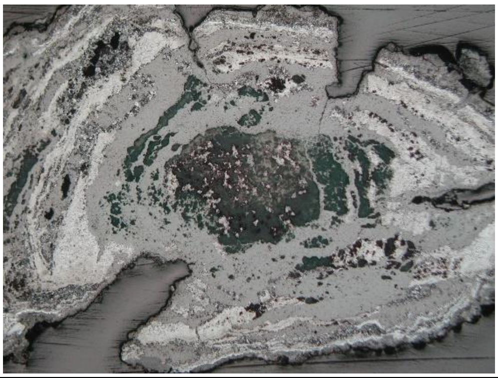
Fragment from plano-convex/ovoid cross-section ring (Type IIb).

Metallography

The sample is completely corroded with no metal preserved. Meanwhile, destructive corrosion layers have disrupted the metal microstructure and the sample's original surface.

However, limited ghost structures at the sample's core have preserved traces of angular grains. In addition, small sulphide inclusions were noted amongst the corrosion layers.

Magn: 50x Im.W.: 3.5 mm



Magn: 100x Im.W.: 1.8 mm

AE 34

Macroscopic characterisation

description	ring
EPMA no.	64
metal	leaded bronze
Wgt	0.52 gr
Th (min)	0.18 cm
Th (max)	0.21 cm
D	1.75 cm
Corrosion	C

Simple, round cross-section wire ring (fragmented) (Type Ia). Its thickness varies in the range of 0.03 cm.

Metallography

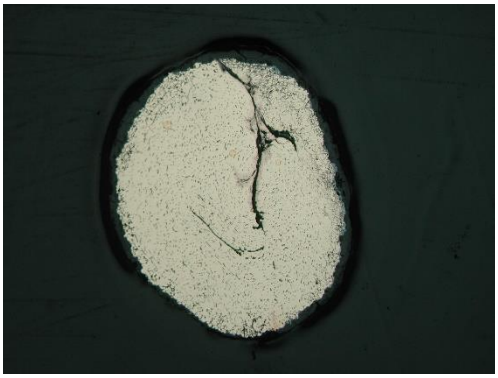
The sample was cut from one of the ring's fragmented ends and its cross-section was embedded in the resin block.

The sample revealed an ovoid cross-section with signs of mechanical stress, while the metal wire seems to have been folded and hammered again to shape as seen by a crack in the middle of the ring and the stressed grains in the place of joint on the surface.

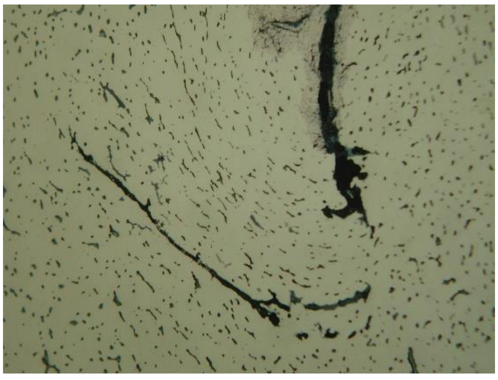
In the substrate, polygonal grains with strain lines and annealing twins are visible. In the metal core, several lead and sulphide inclusions are visible which also follow the shape into which the ring wire has been hammered.

Corrosion: A thin patina layer has covered the whole sample, but no growth/destructive corrosion was found. Inter- and intra-granular corrosion has highlighted the metal grain microstructure.

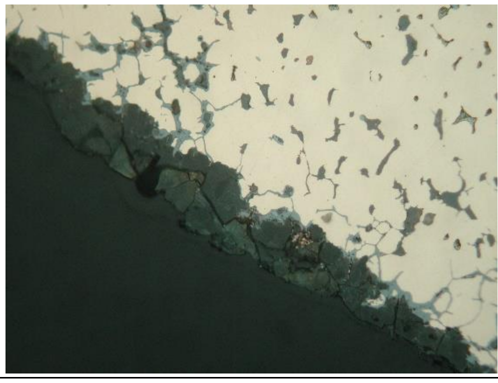
Magn: 50x Im.W.: 3.5 mm



Magn: 200x Im.W.: 0.9 mm



Magn: 500x Im.W.: 350 µm



AE 37

Macroscopic characterisation

description	ring
EPMA no.	77
metal	bronze
Wgt	1.84 gr
Th	0.20 cm
D	2.55 cm
Corrosion	B

Simple, round cross-section wire ring (Type Ia) with open ends.

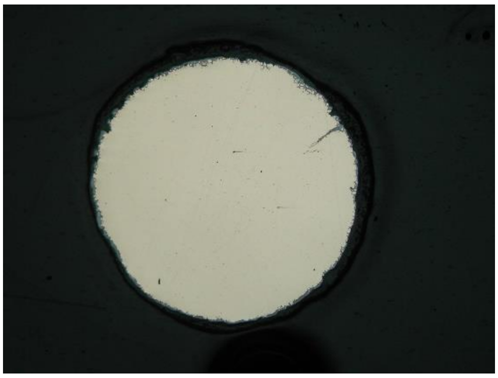
Metallography

The sample was cut from one of the ring’s open ends and its cross-section has been embedded in the resin block.

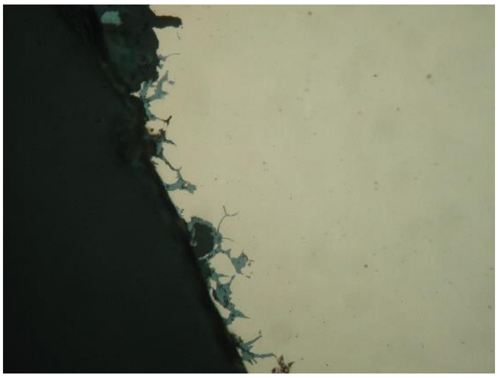
The sample revealed an almost perfect round cross-section which has not been often found within the rest of the sample. The metal, as seen in the substrate, forms grains with limited triple points but with no further strain lines or annealing twins. Lead/sulphide inclusions have been also found and are of several sizes.

Corrosion: The sample’s state of preservation is very good as most of the metal has not been affected, while only the surface has been covered with a thin patina and limited inter-granular corrosion in the substrate. Additionally, some pure copper has precipitated on the sample’s surface as the result of corrosion.

Magn: 50x Im.W.: 3.5 mm



Magn: 500x Im.W.: 350 μm



AE 48

Macroscopic characterisation

description	ring
EPMA no.	(not included)
metal	corroded
Wgt	0.43 gr
Th	0.20 cm
Wdt	0.30 cm
D	1.90 cm
Corrosion	D

Ring with triangular cross-section (Type IIa).

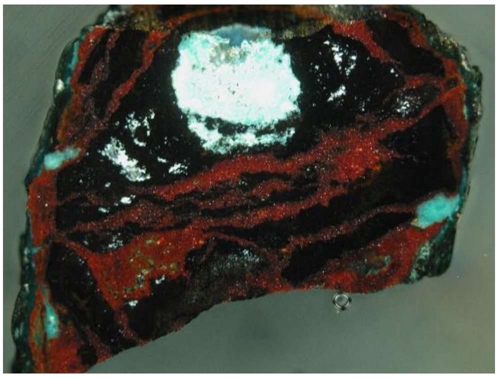
Metallography

The sample was cut from one of the ring's fragmented ends and its cross-section was embedded in the resin block.

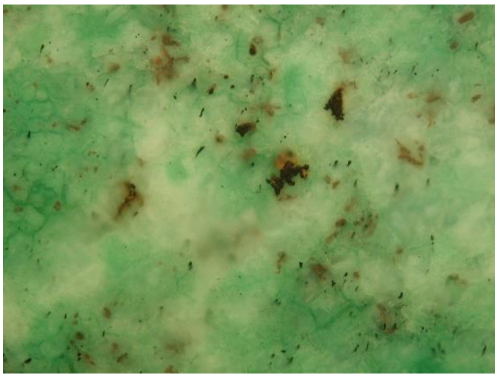
Microscopic examination revealed a completely corroded sample with no sound metal preserved. Only specks of metal have been preserved.

Corrosion: The metal has been substituted by destructive corrosion layers throughout, while the original surface has been severely disrupted. Chlorides have substituted the ring's core which have also preserved traces of a grain microstructure with small, polygonal/angular metal grains with several elongated sulphide inclusions, while mostly destructive oxide red and black layers have affected the rest of the sample.

Magn: 50x	Im.W.: 3.5 mm	Magn: 50x	Im.W.: 3.5 mm, XPL



Magn: 500x	Im.W.: 350 µm	Magn: 500x	Im.W.: 350 µm, XPL



AE 66

Macroscopic characterisation

description	metal sheet
EPMA no.	82
metal	bronze
Wgt	2.10 gr
Th	0.05 cm
Wdt	1.7 cm
L	6.3 cm
Corrosion	B

Fragmented, very thin metal sheet.

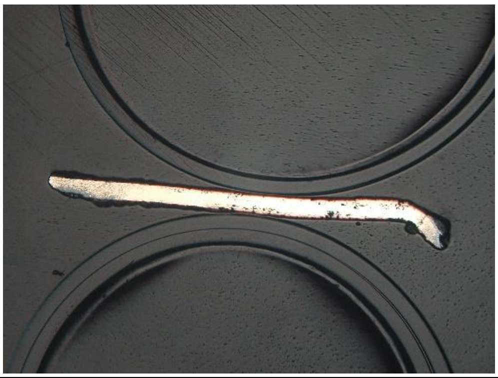
Metallography

Sample was cut from one of the metal sheet's open ends and its cross section was embedded in the resin block.

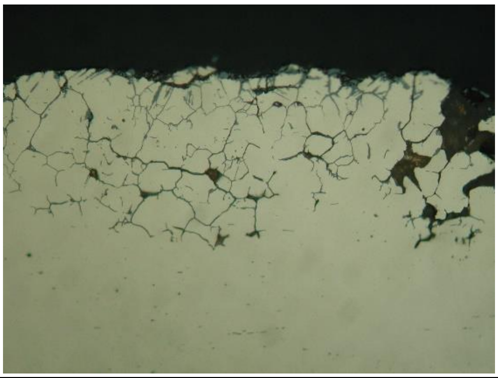
Inter-granular corrosion revealed the microstructure which consists of metallic grains which are of small size and of angular shape, while very few strain lines have been found. Inclusions (lead and sulphide) appeared quite elongated following the direction of the sheet's hammering.

Corrosion: the sample is relatively well preserved, which is rather striking taking into consideration its very small thickness. Surface patina and limited, thin growth corrosion layers are visible. The metal structure is rather affected by corrosion products closer to the surface, while the core is intact.

Magn: 25x Im.W.: 7 mm



Magn: 500x Im.W.: 350 μm



AE 97

Macroscopic characterisation

description	ring
EPMA no.	70
metal	bronze
Wgt	1.19 gr
Th	0.20 cm
D	2.10 cm
Corrosion	B

Simple, round cross-section wire ring (Type Ia) with open ends.

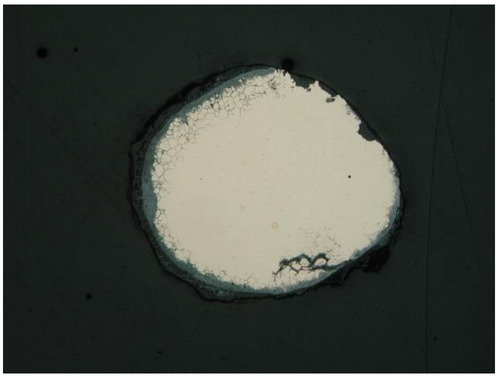
Metallography

The sample was cut from one of the ring's open ends and its cross-section was embedded in the resin block.

The sample revealed a round/ovoid cross section. The metal microstructure consists of grains with strain lines, annealing twins and triple points with small lead/sulphide inclusions.

Corrosion: A thin patina covers the whole sample's surface. Limited destructive

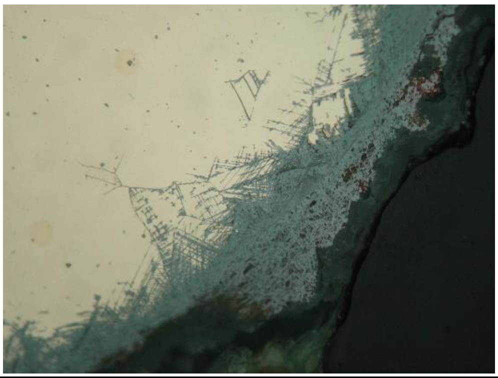
Magn: 50x Im.W.: 3.5 mm



corrosion has affected the substrate layers, while inter- and intra-granular corrosion has highlighted the stressed grains.

Magn: 500x Im.W.: 350 μm

Magn: 500x Im.W.: 350 μm



AE 98

Macroscopic characterisation

description	ring
EPMA no.	68
metal	bronze
Wgt	1.03 gr
Th	0.18 cm
D	2.10 cm
Corrosion	B

Simple, round cross-section wire ring (Type Ia) with open ends.

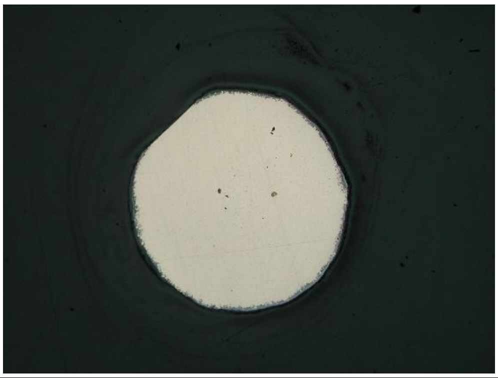
Metallography

The sample was cut from one of the ring's open ends and its cross-section was embedded in the resin block.

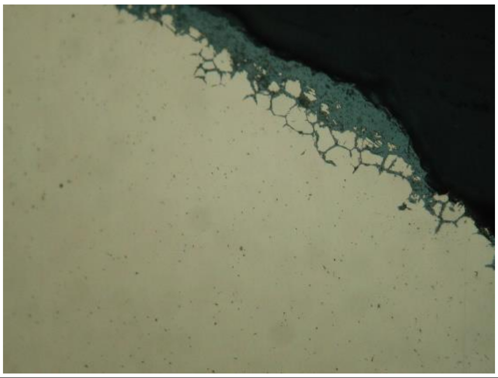
The sample revealed a round cross section, while it is rather flat/straight at a point possibly pointing to its hammering on a flat surface. The metal microstructure consists of small, angular grains with small lead/sulphide inclusions.

Corrosion: A thin patina covers the whole sample's surface, while inter- and intra-granular corrosion has highlighted the grain microstructure.

Magn: 50x Im.W.: 3.5 mm



Magn: 500x Im.W.: 350 μm



AE 103

Macroscopic characterisation

description	ring
EPMA no.	9
metal	bronze
Wgt	1.08 gr
Th	0.20 cm
D	1.90 cm
Corrosion	C

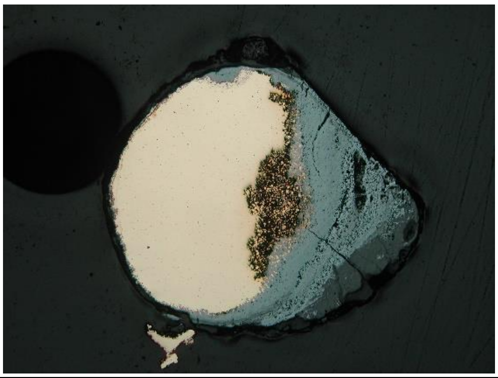
Ring of thin, round wire with open ends (Type Ia).

Metallography

The sample was removed from one of the open ends of the ring, and its cross section was polished in the resin block. The sample revealed a round cross section for the ring with metallic grains of quite small size. In the sound metal, small and rather angular grains are revealed, while no equiaxed structured was found. Similarly, any lead and sulphide inclusions are also minute and not severely deformed, but instead rather with rather rounded edges.

Corrosion: Selective corrosion, possibly related to the ring's burial environmental, has affected mostly one side of the ring's cross section where both the metallic grains have been substituted by corrosion products and growth corrosion layers have severely altered the object's original surface. On the rest of the sample, the surface is covered by a thin patina layer. Most of the metal is well-preserved, while substrate layers are affected by inter-granular and limited intra-granular corrosion. On the corroded side, the metallic grain microstructure has been pseudomorphically substituted by corrosion products, thus, forming 'ghost' structures which in places reveal an equiaxed grain structure. Growth corrosion layers form of copper and tin oxides and chlorides

Magn: 50x Im.W.: 3.5 mm



Magn: 500x Im.W.: 350 µm

AE 107

Macroscopic characterisation

description	spiral ring
EPMA no.	66
metal	bronze
Wgt	5.20 gr
Th	0.20 cm
Wdt	1.05 cm
L	2.5 cm
D	2.0 cm
Corrosion	A

Spiral ring with plano-convex/triangular cross-section (Type Va). Three spirals have been preserved.

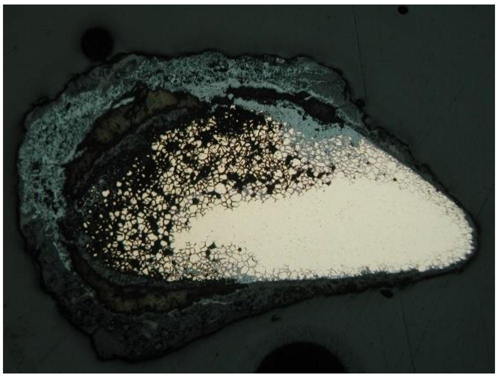
Metallography

The sample was cut from one of the ring's open ends and its cross-section was embedded in the resin block.

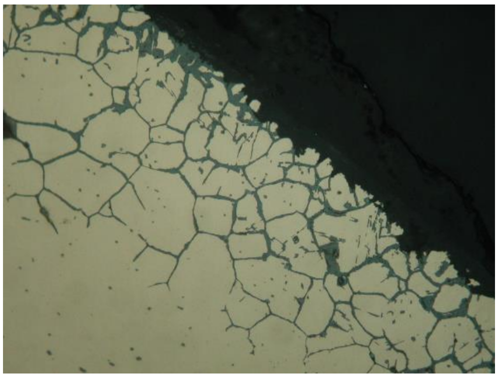
The sample revealed a plano-convex/ triangular cross-section as also noted macro-scopically. Polygonal/ angular metallic grains are visible, often with triple points and strain lines. Several lead/sulphide inclusions are also visible.

Corrosion: The sample is severely corroded on its one side which is covered with thick growth corrosion layers, while benign corrosion has replaced the metal microstructure. On the opposite side, the sample is better preserved with only surface patina and limited inter-granular corrosion in the substrate.

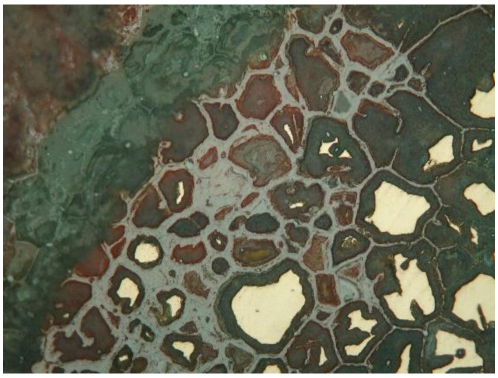
Magn: 50x Im.W.: 3.5 mm



Magn: 500x Im.W.: 350 µm



Magn: 500x Im.W.: 350 µm



AE 113

Macroscopic characterisation

description	ring
EPMA no.	37
metal	bronze
Wgt	1.65 gr
Th	0.20 cm
D	2.50 cm
Corrosion	A

Simple, round cross-section wire ring (Type Ia) with open ends.

Metallography

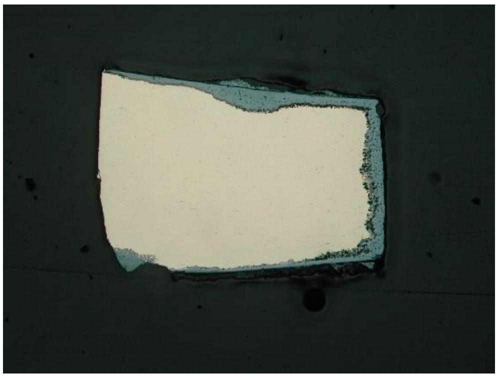
tangential section

The sample was cut from one of the ring's open ends and its tangential section was embedded in the resin block.

The metal revealed quite small metal grains with limited strain lines and some triple points. As the result of hammering and since the ring's tangential section has been examined, several lead/sulphide inclusions with thin, elongated shape have been revealed. Some lead inclusions have a square cross-section pointing to the hammering pattern from two opposite sides.

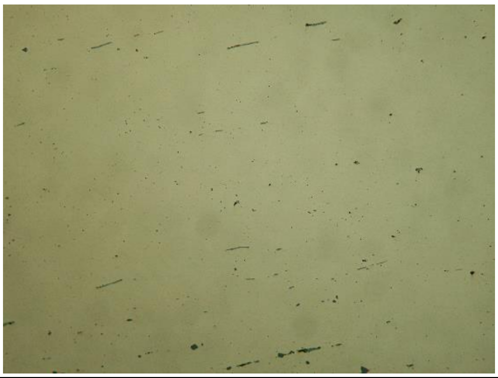
Corrosion: The sample is well preserved with a substantial metallic core. The substrate has been replaced by corrosion products which preserved the ring's original surface, which is further covered by a thin patina layer.

Magn: 50x Im.W.: 3.5 mm



Magn: 500x Im.W.: 350 µm

Magn: 500x Im.W.: 350 µm



AE 246

Macroscopic characterisation

description	ring
EPMA no.	19
metal	bronze
Wgt	0.58 gr
Th (min)	0.18 cm
Th (max)	0.30 cm
D	1.85 cm
Corrosion	C

Simple, round cross-section wire ring (Type Ia) with open ends.

Metallography

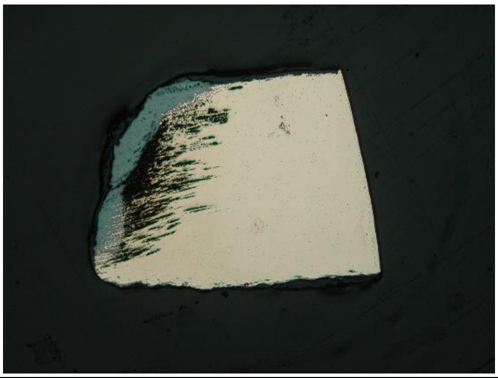
The sample was cut from one of the ring's fragmented ends and its tangential section was embedded in the resin block.

The metal revealed a structure of quite small, polygonal/angular grains, often with triple points. Corrosion has not highlighted further any strain lines or annealing twins. In the metal, few sulphide and lead inclusions were noted which were typically very small as well.

Corrosion: Selective corrosion has affected the ring's end and not so much its sides. The whole sample is covered by a thin patina layer, while its end has been affected by limited destructive corrosion. Inter-granular corrosion has further highlighted the grains whose elongated pattern is taken as a result of the hammering.

	Magn: 50x	Im.W.: 3.5 mm	Magn: 500x	Im.W.: 350 µm

tangential section



AE 249

Macroscopic characterisation

description	metal sheet
EPMA no.	73
metal	bronze
Wgt	0.67 gr
Th (min)	0.04 cm
Th (max)	0.05 cm
Wdt	1.35 cm
L	1.8 cm
Corrosion	B

Thin metal sheet fragment.

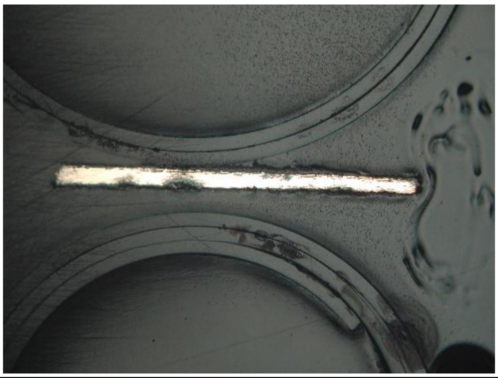
Metallography

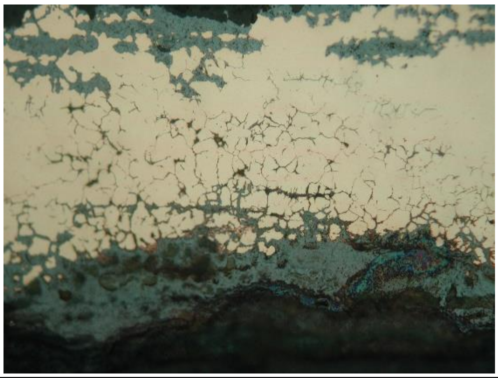
The sample was cut from one of the sheet's fragmented sides and its cross-section was embedded in the resin block.

The metal revealed a small, polygonal/angular grain microstructure. Several thin, elongated sulphide inclusions are present in the metal. No strain lines or annealing twins have been noted.

Corrosion: A metal core is preserved. Inter- and intra-granular corrosion have highlighted the metallic grains throughout the sample. Few pure copper prills have precipitated on the sample as the result of corrosion processes. The sample is covered by a thin patina layer, and limited growth corrosion layers.

	Magn: 25x	Im.W.: 7 mm	Magn: 500x	Im.W.: 350 µm





AE 289

Macroscopic characterisation

description	metal sheet
EPMA no.	27
metal	bronze
Wgt	1.75 gr
Th (min)	0.05 cm
Th (max)	0.10 cm
Wdt	2.00 cm
L	3.00 cm
Corrosion	B

Thin metal sheet fragment.

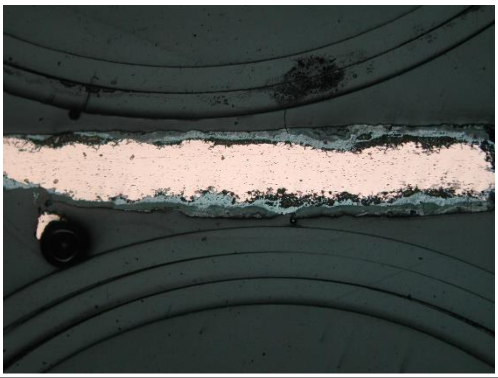
Metallography

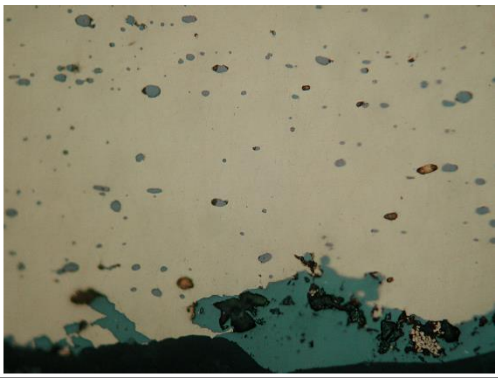
The sample was cut from one of the sheet's fragmented sides and its cross-section was embedded in the resin block.

The metal core revealed several, rather large sulphide inclusions and fewer lead inclusions of round cross-sections. The sheet's surface is not as even even/flat as seen in other metal sheets in the analysed assemblage. Corrosion has highlighted some quite angular grains in the substrate.

Corrosion: A substantial metal core is preserved, while limited corrosion in the substrate has disrupted the samples original surface.

Magn: 50x	Im.W.: 5 mm	Magn: 500x	Im.W.: 350 µm





AE 459

Macroscopic characterisation

description	ring
EPMA no.	21
metal	bronze
Wgt	3.15 gr
Th (min)	0.20 cm
Wdt	0.5 cm
D	2.40 cm
Corrosion	A

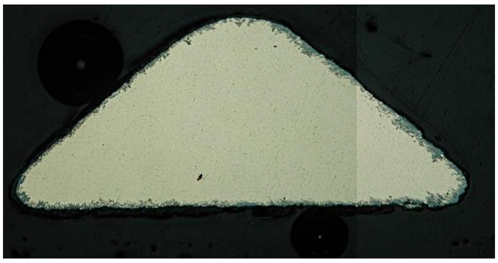
Ring with triangular cross-section and open ends (Type Ia).

Metallography

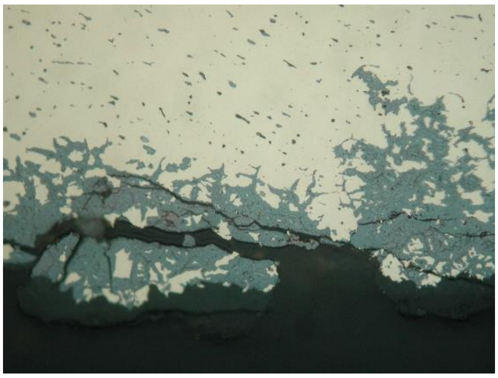
The sample's cross-section revealed a symmetrical triangular shape which is quite different from the plano-convex rings included in the analysed assemblage. The sample is covered by a very thin patina layer, while its state of preservation is very good. Several sulphide and lead inclusions are noted in the sound metal which are of thin, elongated and/or angular shape as the result of the repeated which would have taken place in order to produce this triangular cross-section.

Inter-granular corrosion in the substrate of the sample, has revealed small, angular metallic grains often with triple points and few strain lines.

Magn: 50x Im.W.: 5 mm



Magn: 500x Im.W.: 350 µm



AE 480

Macroscopic characterisation

description	metal sheet
EPMA no.	76
metal	bronze
Wgt	2.75 gr
Th (min)	0.06 cm
Th (max)	0.12 cm
Wdt	2.15 cm
L	1.90 cm
Corrosion	B

Thin metal sheet fragment.

Metallography

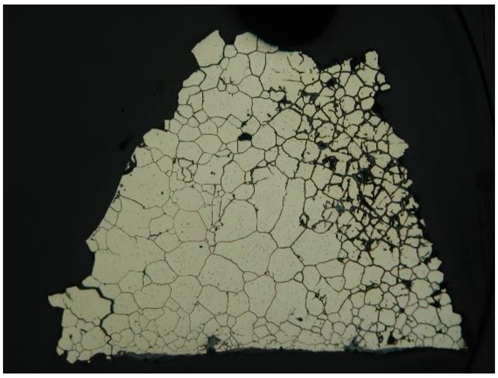
Both a cross-section and a tangential section of the sample have been embedded in the resin block and have been polished together.

The metal revealed a grain microstructure with large grains and clear boundaries, as wel as with several minute lead and sulphide inclusions.

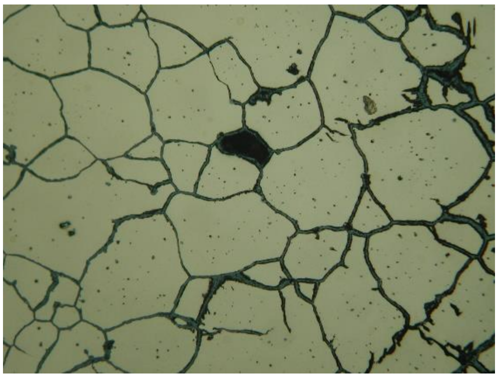
Corrosion: Limited surface corrosion layers were noted in the cross0-section, while the samples are typically covered with a thin patina. Inter-granular corrosion has affected the samples throughout.

tangential section

Magn: 50x Im.W.: 3.5 mm

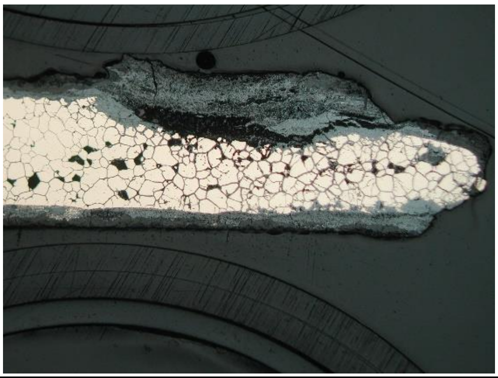


Magn: 200x Im.W.: 0.9 mm

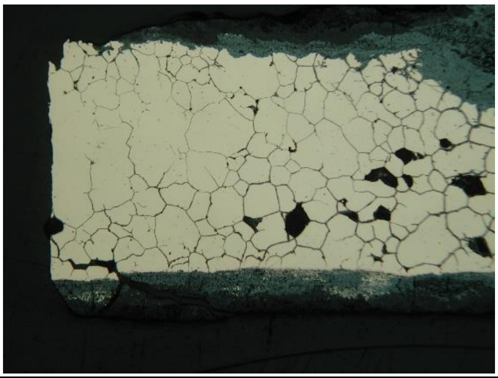


cross-section

Magn: 50x Im.W.: 3.5 mm



Magn: 100x Im.W.: 1.8 mm



AE 506

Macroscopic characterisation

description	ring
EPMA no.	42
metal	leaded bronze
Wgt	0.84 gr
Th	0.20 cm
Wdt	0.25 cm
L	1.6 cm
D	1.3 cm
Corrosion	A

Ring with thick, round cross-section and open ends (Type IVa).

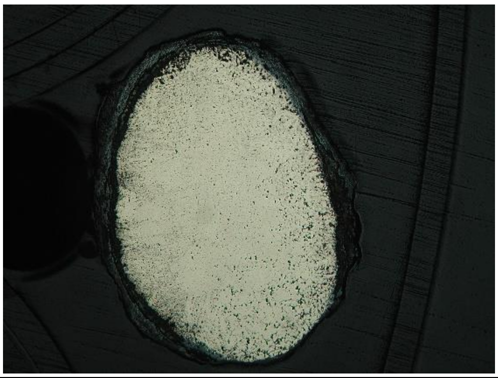
Metallography

The sample's cross-section revealed an ovoid shape.

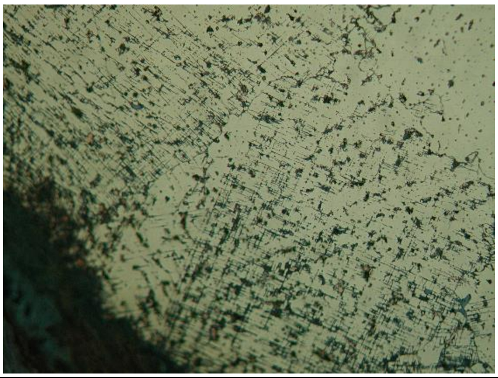
The metal consists if rather thin and long dendrites from casting while few, small, and angular stressed grains with strain lines are visible in the sample's substrate as the result of surface hammering to shape. Several, small, rounded lead and sulphide inclusions are also visible. Finally, small gas-holes seem to precipitate between dendrite boundaries.

Corrosion: Few pure copper prill have precipitated on the sample's surface as the result of corrosion processes.

Magn: 50x Im.W.: 3.5 mm



Magn: 500x Im.W.: 350 µm



AE 507

Macroscopic characterisation

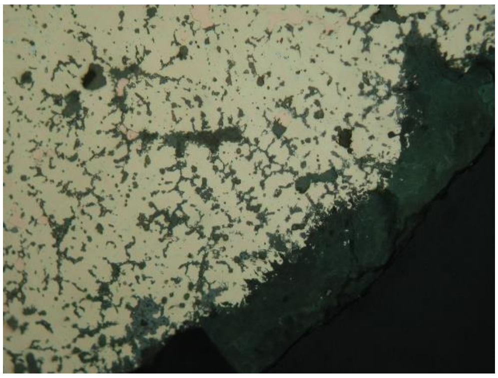
description	ring
EPMA no.	60
metal	leaded bronze
Wgt	0.56 gr
Th	0.15 cm
Wdt	0.20 cm
D	2.40 cm
Corrosion	A

Simple round wire ring (Type Ia). Half of the ring is preserved.

Metallography

The sample was cut from one of the ring's open ends and its cross section was embedded and polished in the resin block. The sample revealed an ovoid cross section with traces of an as cast structure with little working of the surface and substrate layers emphasising, thus, the simple method of manufacturing for this ring. Thick dendrites are highlighted by corrosion products throughout the cross section. The sample's original surface has been preserved by a layer of corrosion patina.

Magn: 100x Im.W.: 1.8 mm Magn: 500x Im.W.: 350 μm



AE 514

Macroscopic characterisation

description	disk
EPMA no.	46
metal	bronze
Wgt	2.16 gr
Th (min)	0.09 cm
Th (max)	0.18 cm
Wdt	1.75 cm
L	2.5 cm
D	3.00 cm
Corrosion	B

Fragment of small disk with traces of embossed decoration and central suspension hole. Possibly a wheel disk pendant or a decorative ornament of a spectacle fibula.

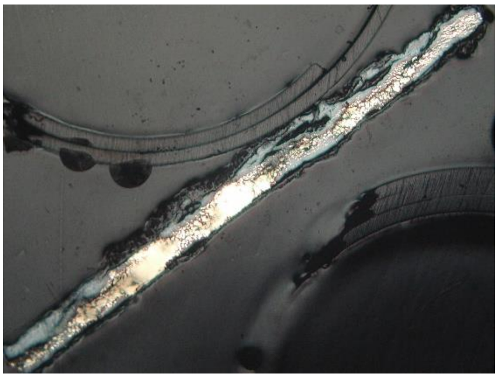
See also disk AE 427 in Appendix III.2 and Blinkenberg (1926, p.259, fig. 305).

Metallography

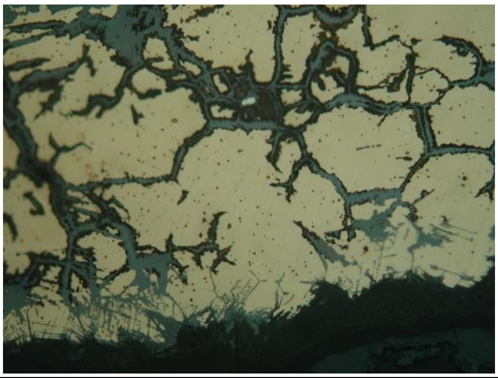
The sample's cross-section revealed a polygonal/angular grain microstructure with triple points and strain lines. Several lead and sulphide small, angular inclusions were noted too. Metal grains are larger in the metal core and smaller and more stressed towards the sample's surface.

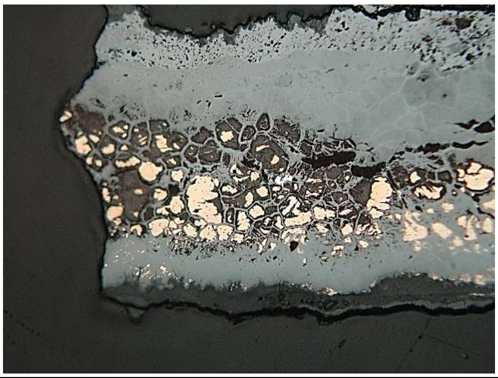
Corrosion: The sample's core has been affected by inter-granular and benign corrosion which have preserved its original microstructure. The samples substrate has been substituted by destructive corrosion, while growth corrosion layers have precipitated on its surface.

Magn: 25x Im.W.: 7mm



Magn: 500x	Im.W.: 350 µm	Magn: 200x	Im.W.: 0.9 mm





AE 549

Macroscopic characterisation

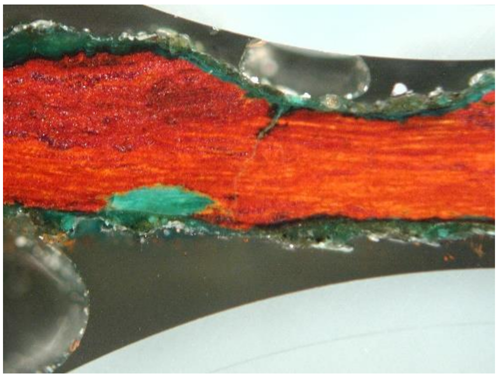
description	metal sheet
EPMA no.	22
metal	bronze (corroded)
Wgt	7.02 gr
Th (min)	0.08 cm
Wdt	3.50 cm
L	4.50 cm
H	0.50 cm
Corrosion	D

Thin metal sheet fragments.

Metallography

The embedded sample was found corroded throughout and fragmented. Destructive corrosion layers have substituted the metal, but they have preserved the sheet's original surface in places. Few elongated, thin sulphide inclusions have been preserved in the corrosion products.

Magn: 25x	Im.W.: 7mm	Magn: 100x	Im.W.: 1.8 mm, XPL



AE 564

Macroscopic characterisation

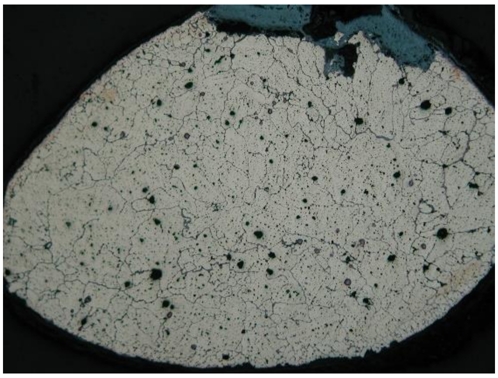
description	ring
EPMA no.	17
metal	bronze
Wgt	5.17 gr
Th (min)	0.25 cm
Th (max)	0.30 cm
Wdt	0.40 cm
D	3.40 cm
Corrosion	A

Ring with thick, round cross-section and decorative projections (Type IVb).

Metallography

The ring's cross-section revealed an ovoid shape with one side being pointier than the opposite.

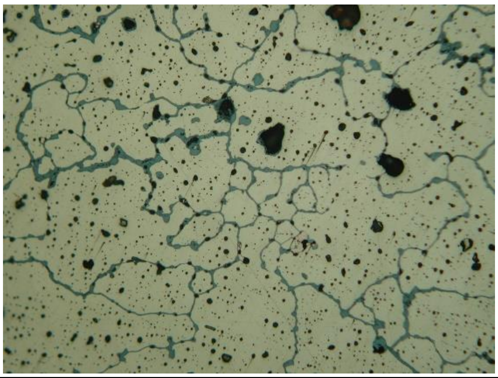
Magn: 50x Im.W.: 3.5 mm



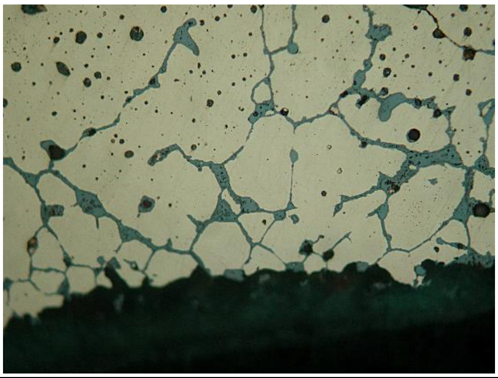
The metal consists of large α-grains and includes several large gas-holes which typically precipitate between grain boundaries. Several, large, round lead inclusions are visible, along with smaller sulphide ones. Few polygonal grains are visible in the sample's surface as the result of surface treatment/hammering.

Corrosion: The sample is relatively well preserved, while inter-granular corrosion has highlighted its microstructure throughout. A thin patina covers the sample's surface.

Magn: 200x Im.W.: 1.8 mm



Magn: 500x Im.W.: 350 µm



AE 578

Macroscopic characterisation

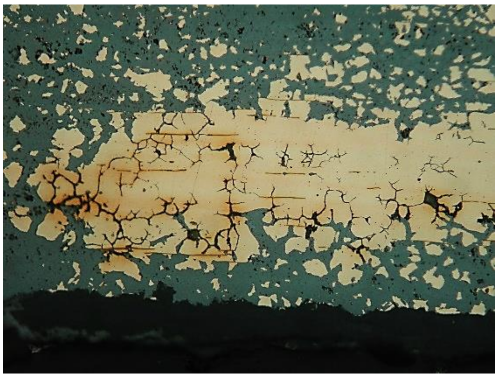
description	metal sheet
EPMA no.	44
metal	bronze
Wgt	2.40 gr
Th (min)	0.05 cm
Th (max)	0.10 cm
Wdt	2.7 cm
L	4.20 cm
H	0.70 cm
Corrosion	B

Thin metal sheet fragment.

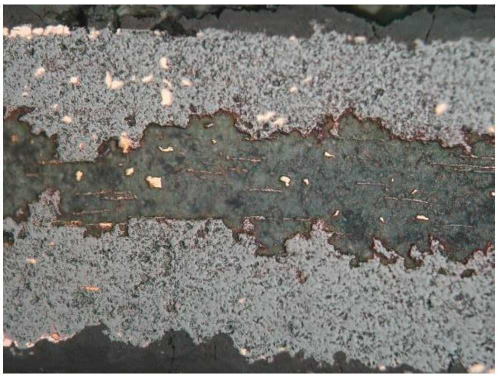
Metallography

The sheet's cross-section revealed a relatively well preserved metal core formed of small, angular grains with long, thin, elongated sulphide inclusions which have been preserved in corrosion layers too.
Corrosion: Part of the sample has been substituted by destructive corrosion layers, but considerable metallic core has been preserved as well. Destructive corrosion has affected the substrate, while benign corrosion has affected the sample's core. The sheet's original surface has been preserved in corrosion products too. Thin growth corrosion layers have precipitated on the sample's surface.

Magn: 500x Im.W.: 350 μm



Magn: 500x Im.W.: 350 μm



AE 597

Macroscopic characterisation

description	ring
EPMA no.	56
metal	bronze
Wgt	0.32 gr
Th	0.15 cm
L	1.45 cm
Corrosion	C

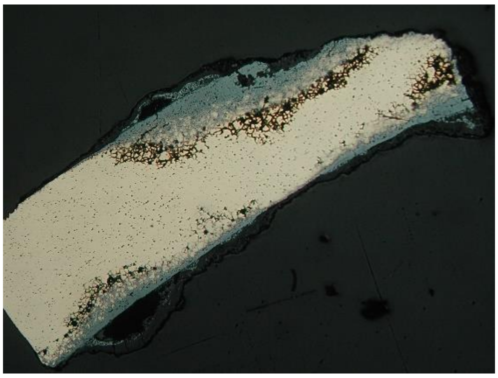
Simple round wire ring (Type Ia), fragmented and half preserved.

Metallography

Tangential section

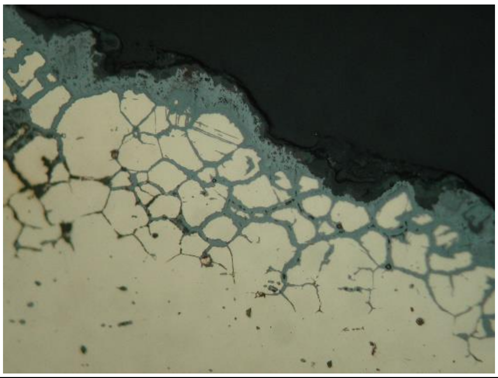
The sample was cut from one of the fragmented ring's open ends. The sample showed that most of the metal is preserved. The metallic microstructure has been highlighted by corrosion products which revealed, polygonal/angular metallic grains typically of small size. Metallic grains showed strains lines and few annealing twins. In the sound metal, several lead and sulphide inclusions were found. Lead inclusions are rather more round than the sulphide ones which are long, thin and elongated, and follow the direction of the metal wire as a result of the hammering.

Magn: 50x Im.W.: 3.5 mm



Magn: 200x Im.W.: 0.9 mm

Magn: 500x Im.W.: 350 µm



AE 606

Macroscopic characterisation

description	metal sheet
EPMA no.	29
metal	bronze
Wgt	7.05 cm
Th (min)	0.15 cm
Th (max)	0.50 cm
Wdt	1.00 cm
L	3.05 cm
H	1.00 cm
Corrosion	B

Fragment of metal sheet which forms an angle with a clear edge on the exterior side. Possibly a vessel fragment.

Metallography

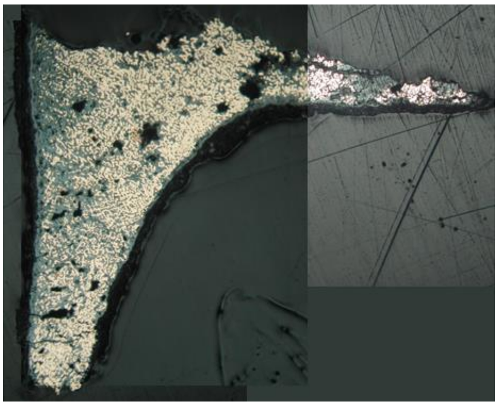
Sample taken from the side of the fragment. Cross section was polished in the resin block which reveals further the fragments angle. The sound metal forms dendrites and α-grains in places as the result of its casting. The dendrites' shape reveals a rather fast cooling rate particularly close to the surface, suggesting that no further metalworking took place after removing the object from the mould. In the dendritic structure, more gas-holes are visible than amongst the α-grains. A small number of minute sulphide inclusions is visible in the metal.

One the outside surface of the fragment (vertical, left side in the 25x photomicrograph below) a thin layer of tenorite (black copper oxide) forms, possibly suggesting that the vessel could have been used close to an open fire.

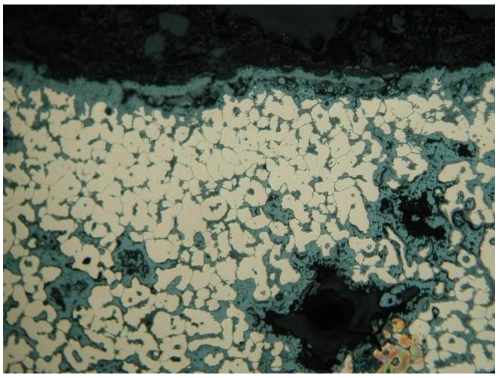
Corrosion: Selective corrosion has highlighted the dendrites and metallic grains. Thin growth corrosion layers have formed on the sample's surface (cuprite, tenorite, green copper salts).

See also M 1217 C for a similar microstructure.

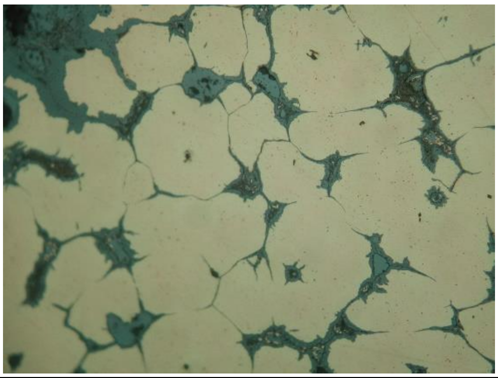
Magn: 25x Im.W.: 12 mm



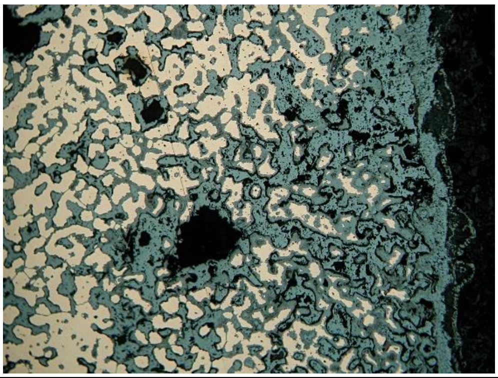
Magn: 100x Im.W.: 1.8 mm



Magn: 500x Im.W.: 350 µm



Magn: 100x Im.W.: 1.8 mm



AE 619

Macroscopic characterisation

description	metal sheet
EPMA no.	54
metal	bronze
Wgt	0.56 gr
Th	0.08 cm
Wdt	0.50 cm
L	2.10 cm

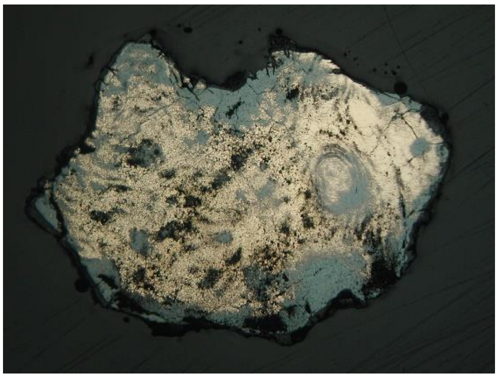
Fragment of plano-convex metal sheet forming a small scoop. Possibly from small tool.

H 0.20 cm

Corrosion C

Metallography

Magn: 25x Im.W.: 7 mm

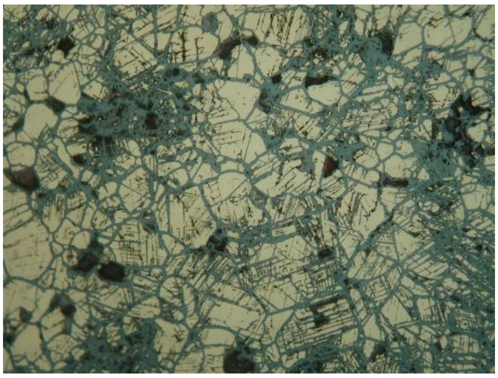


tangential section

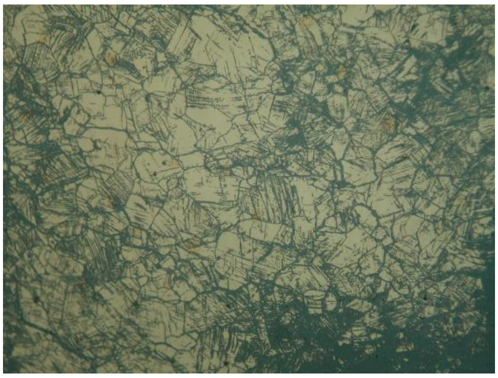
The sample was removed from the fragmented end of the metal sheet and a tangential section was polished in order to allow for a larger area to be examined.

Even though the sample is corroded throughout, inter- and intra-granular corrosion has preserved a large metallic area with small metallic grains with strain lines and annealing twins. Grains are angular/polygonal. Some sulphide inclusions were noted but no significant amount of lead prills.

Magn: 500x Im.W.: 350 µm



Magn: 500x Im.W.: 350 µm



AE 624

Macroscopic characterisation

description spiral ring

EPMA no. 63

metal bronze

Wgt 2.31 gr

Th 0.20 cm

Wdt 0.30 cm

D 2.00 cm

Corrosion B

Triangular cross-section spiral ring with two spirals preserved (Type Va).

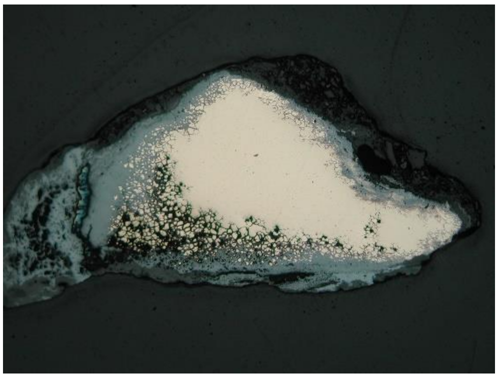
Metallography

The embedded cross-section revealed the triangular shape also noted macroscopically.

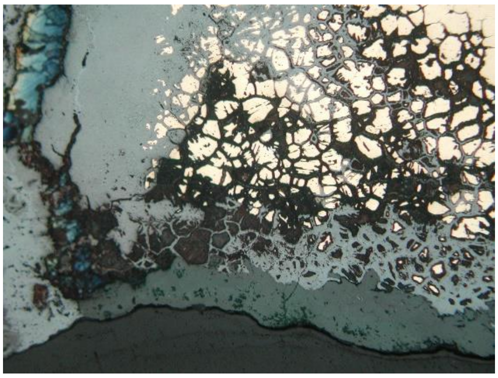
The sample consists of a metallic grain microstructure with small polygonal/angular grains with strain lines. Several, small sulphide inclusions are also visible.

Corrosion: Thick growth corrosion layers precipitate on the sample's surface. Inter-granular and benign corrosion have highlighted the metal microstructure.

Magn: 50x Im.W.: 3.5 mm

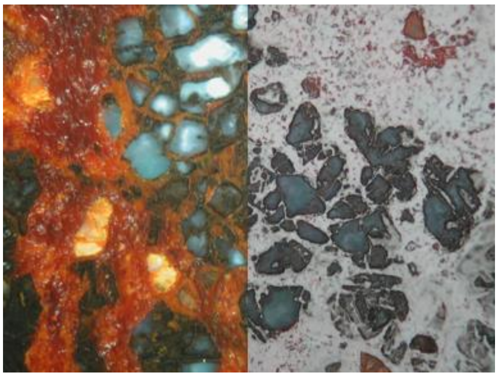


Magn: 200x Im.W.: 0.9 mm



Magn: 500x Im.W.: 350 µm

XPL PPL



AE 633.1

Macroscopic characterisation

description	ring
EPMA no.	33
metal	bronze
Wgt	0.23 gr
Th	0.10 cm
L	1.6 cm
Corrosion	B

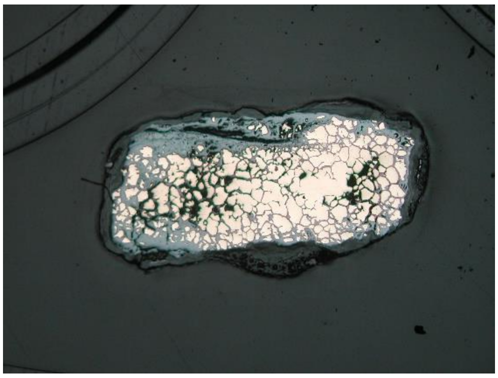
Fragment of wire with rectangular cross-section. Possibly part of ring of Type Ia.

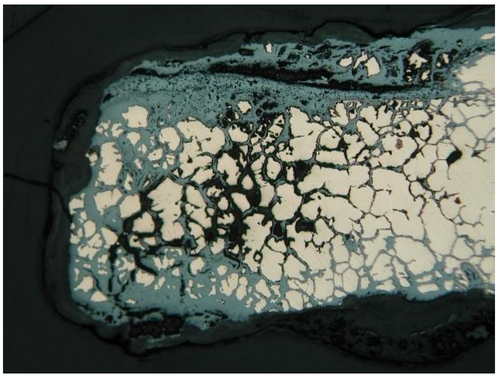
Metallography

The sample's polished cross-section revealed a rectangular shape (as also seen macroscopically). The microstructure consist of large grains in the metal core which become smaller closer to the surface. No strain lines or annealing twins were noted. Few sulphide and lead inclusions are visible.

Corrosion: The sample has been affected by inter-granular corrosion throughout, while some destructive corrosion takes place on its surface which is further covered by thin growth layers.

Magn: 50x	Im.W.: 3.5 mm	Magn: 100x	Im.W.: 1.8 mm





AE 651

Macroscopic characterisation

description	spiral ring
EPMA no.	83
metal	bronze
Wgt	9.86 gr
Th	0.20 cm
L	3.50 cm
D	2.25 cm
Corrosion	C

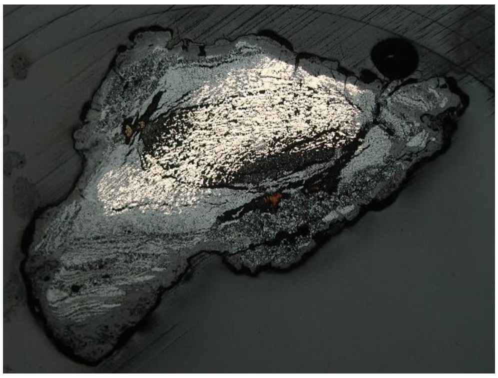
Spiral ring with 7/8 preserved coils with plano-convex cross-section (Type Va).

Metallography

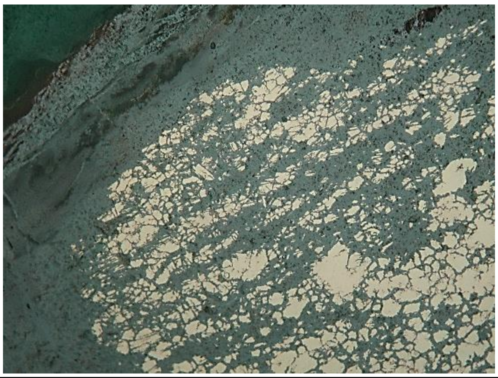
The sample showed a triangular cross-section. The metal consists of small, angular grains often with strain lines. Elongated sulphide inclusions are also present. The overall grain structure seems to follow a certain orientations, most likely as the result of the hammering process.

Corrosion: Growth and destructive corrosion layers have affected the samples original surface. However, inter- and intra-granular corrosion have highlighted the metal microstructure throughout the sample.

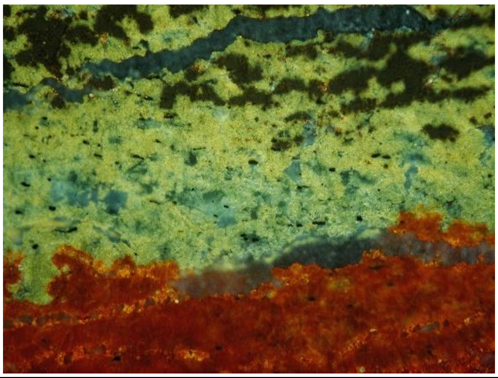
Magn: 50x Im.W.: 3.5 mm



Magn: 500x Im.W.: 350 µm



Magn: 500x Im.W.: 350 µm, XPL



AE 654

Macroscopic characterisation

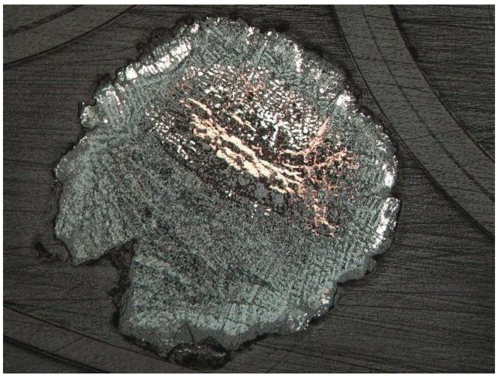
description	ring
EPMA no.	23
metal	bronze
Wgt	1.50 gr
Th	0.25 cm
L	2.00 cm
H	0.80 cm
D	2.30 cm
Corrosion	C

Simple, round cross-section wire ring fragments (Type Ia).

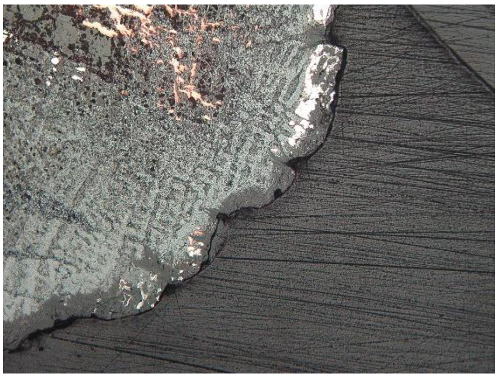
Metallography

The sample's round cross-section is severely corroded throughout. However, benign corrosion has preserved traces of a dendritic structure with thin, long dendrites. Some areas of copper sulphide are visible close to the surface, while pure copper has been re-deposited in the sample's core. Only specks of sound metal are preserved.

Magn: 50x Im.W.: 3.5 mm



Magn: 100x Im.W.: 1.8 mm



AE 666

Macroscopic characterisation

description	nail
EPMA no.	65
metal	bronze
Wgt	1.41 gr
Th (min)	0.20 cm
Th (max)	0.30 cm
L	3.80 cm
Corrosion	C

Small nail with square-cross section, pointy end and plano-convex head.

Metallography

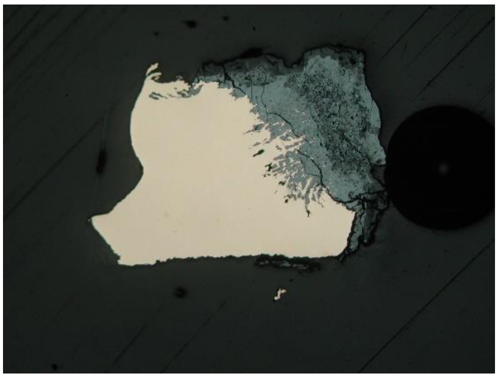
The sample's tangential section revealed a substantial metal core preserved.

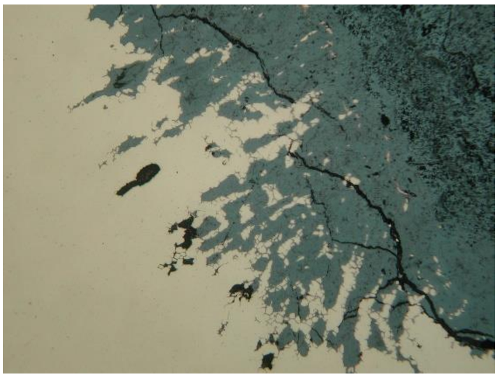
Inter-granular corrosion has highlighted the metal microstructure which consists of particularly small angular metal grains.

Corrosion: Destructive corrosion has substituted part of the sample, leaving though a large area of sound metal intact.

Magn: 50x Im.W.: 3.5 mm Magn: 200x Im.W.: 0.9 mm

tangential section



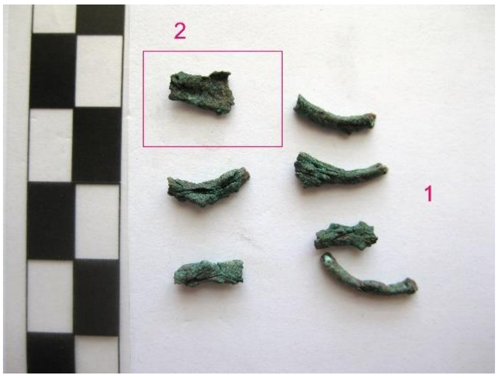


AE 733.1

Macroscopic characterisation

description	ring
EPMA no.	12
metal	bronze
Wgt	1.42 cm
Th (min)	0.17 cm
Th (max)	0.20 cm
L	0.22 cm
Corrosion	D

Fragments of wire (Type Ia) rings and folded sheets.



Metallography

tangential section

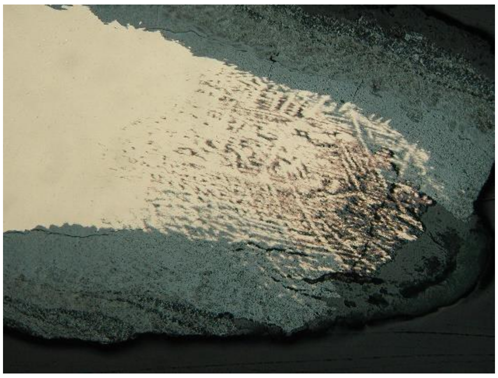
The sample has been taken from a ring fragment.

The polished section has revealed a structure with quite small grains which seem to still follow a dendritic structure. Also, in the cuprite several dendrites have been pseudomorphically replaced.

Corrosion: Limited destructive corrosion takes place in the substrate while inter-granular, inter-dendritic corrosion is also visible.

Magn: 25x Im.W.: 7 mm

Magn: 100x Im.W.: 1.8 mm



Magn: 500x Im.W.: 350 μm

AE 739

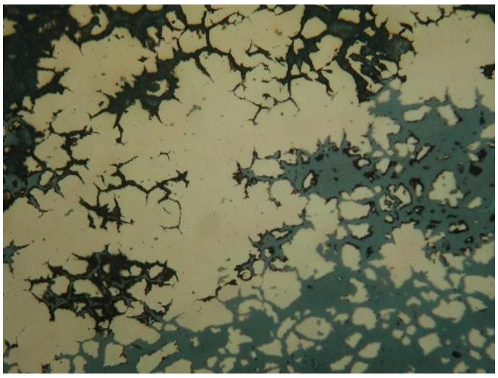
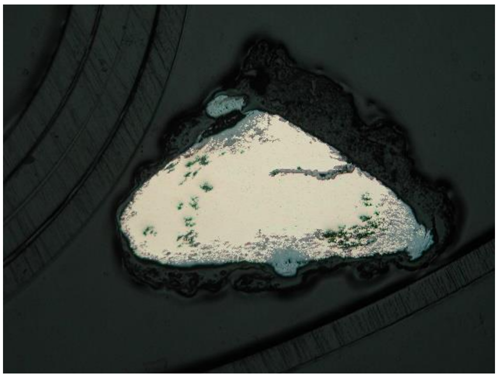
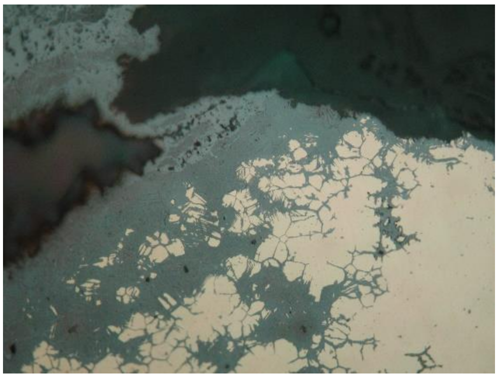
Macroscopic characterisation

description	spiral ring
EPMA no.	4
metal	bronze
Wgt	4.34 gr
Th	0.20 cm
Wdt	0.40 cm
L	2.30 cm
H	1.00 cm
D	2.10 cm
Corrosion	B

Spiral ring with plano-convex/triangular cross-section (Type Va). Three spirals have been preserved.

Metallography

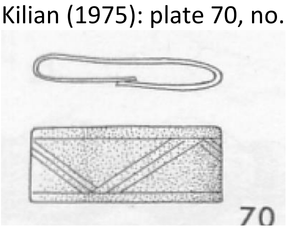
The polished sections revealed a granular structure with quite small, polygonal/angular grains often with triple points. Several minute and often elongated sulphide and lead inclusions are visible. Limited strain lines have been highlighted by intra-granular corrosion.

	Magn: 100x	Im.W.:	Magn: 500x	Im.W.: 350 µm
tangential section				
	Magn: 50x	Im.W.: 3.5 mm	Magn: 500x	Im.W.: 350 µm
cross-section				

AE 743

Macroscopic characterisation

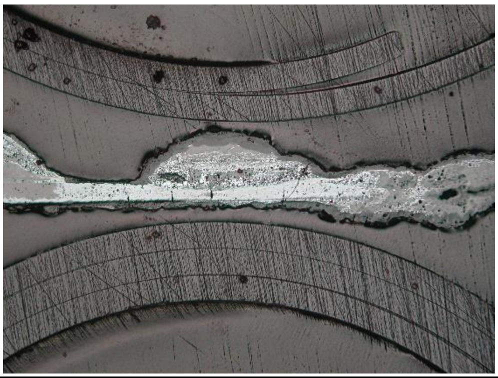
description	ring	Thin sheet metal ring (Type III).
metal	bronze (corroded)	Typology: Kilian (1975): plate 70, no. 70
Wgt	1.05 gr	
Th (min)	0.10 cm	
Wdt	0.90 cm	
L	2.30 cm	
H	1.10 cm	
Corrosion	C	

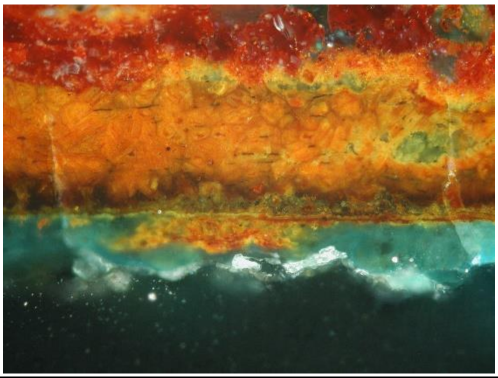


Metallography

Two samples were cut from the ring. Due to their very small thickness, both the polished sections have been corroded throughout. However, in places the sheet’s granular microstructure has been pseudomorphically replaced by corrosion products. The elongated, thin sulphide inclusions have also been preserved. Thick growth corrosion layers have precipitated on the ring’s surface (bronze disease).

	Magn: 50x	Im.W.: 3.5 mm	Magn: 500x	Im.W.: 350 µm, XPL



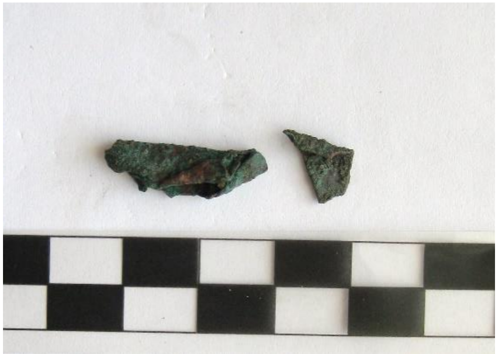


AE 744

Macroscopic characterisation

description	metal sheet (folded)
EPMA no.	84
metal	bronze
Wgt	0.93 gr
Th (min)	0.05 cm
Th (max)	0.12 cm
Wdt	0.70 cm
L	2.10 cm
H	0.45 cm
Corrosion	C

Fragments of folded metal sheet.



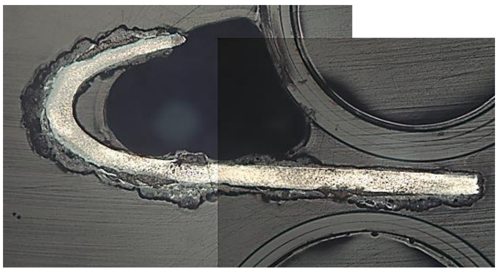
Metallography

Sample was cut from one of the metal sheet fragments and its cross section was embedded in the resin block.

The polished cross section revealed the nature of the folded metal. Despite the sheet's small thickness, it is relatively well preserved and corrosion products have little affected its original surface, while a substantial metallic core was found. Examination revealed a grain microstructure with quite small size grains in which strain lines and annealing twins have been highlighted by intra-granular corrosion. Few, small sulphide and lead inclusions were found.

	Magn: 25x	Im.W.: 10 mm	Magn: 500x	Im.W.: 350 µm

cross section



AE 752

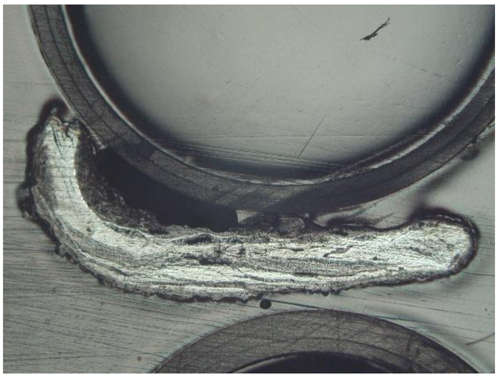
Macroscopic characterisation

description	disk
EPMA no.	48
metal	bronze
Wgt	18.34 gr
Th	0.10 cm
H	0.50 cm
D	8.40 cm
Corrosion	A

Metal decorative disk or possibly miniature shield.

Metallography

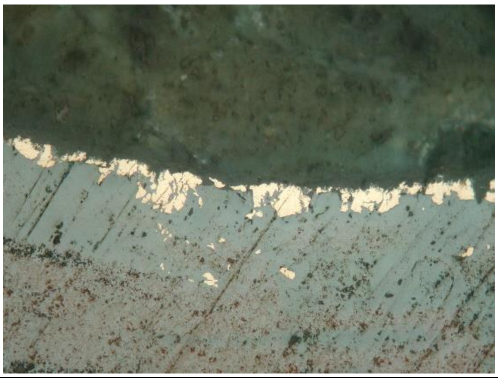
Magn: 25x Im.W.: 7mm



The polished cross-section has been corroded throughout and only specks of metal have been preserved. The sample has been substituted by destructive corrosion layers (typically cuprite), while growth layers have also precipitated on its surface. Finally, no sulphide inclusions are visible in the corrosion products.

Magn: 100x Im.W.: 1.8 mm, XPL

Magn: 500x Im.W.: 350 µm



AE 754

Macroscopic characterisation

description	ring
EPMA no.	74
metal	bronze
Wgt	1.82 gr
Th (min)	0.12 cm
Th (max)	0.20 cm
Wdt	0.45 cm
D of spiral	0.60 cm
Corrosion	C

Type Ib ring with round cross-section and open ends with double spiral decoration. See also AE 838.

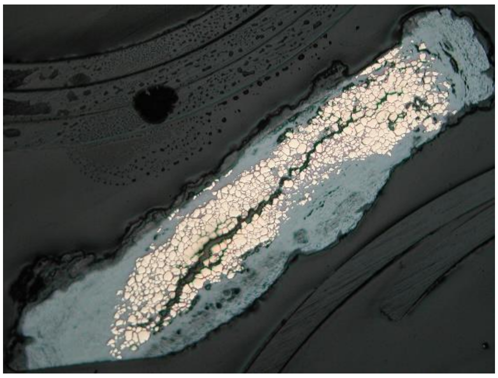
Metallography

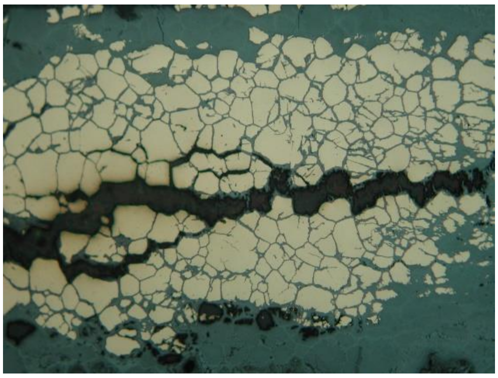
The polished section revealed a granular structure with typically large grains with fewer smaller ones. Triple points are often visible. A large crack runs through the section. Lead and sulphide inclusions are also visible.

Corrosion: Destructive layers are visible in the sample's substrate, while thin growth layers precipitate on its surface. Inter-granular corrosion has highlighted the microstructure.

Magn: 50x Im.W.: 3.5 mm Magn: 200x Im.W.: 0.9 mm

tangential section





AE 760.1

Macroscopic characterisation

description	ring
EPMA no.	67
metal	bronze
Wgt	1.53 gr
Th	0.25 cm
D	1.50 cm
Corrosion	C

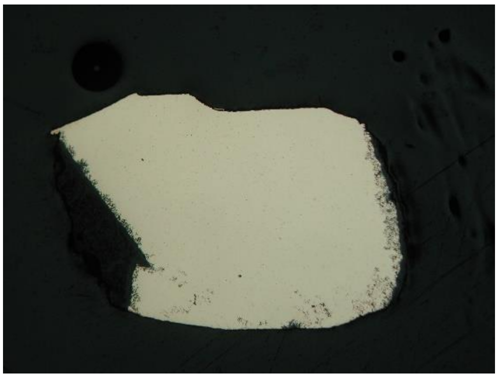
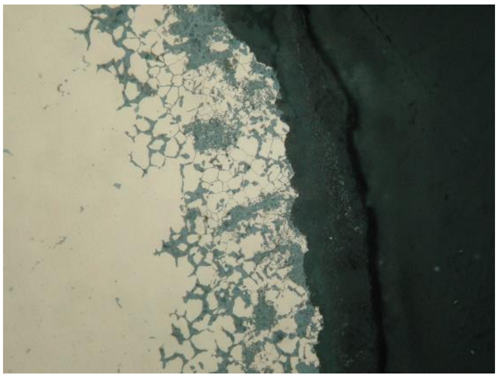
Thick, round cross-section ring with open ends (Type IVa).

Metallography

The sample has very good preservation state.

The sound metal revealed a polygonal/angular grain microstructure, while triple points are occasionally present. Grain size is small. Several, angular and elongated sulphide inclusions are visible.

Corrosion: Very thin patina layer on the surface. Limited inter-granular corrosion in the sample's substrate.

	Magn: 50x	Im.W.: 3.5 mm	Magn: 500x	Im.W.: 350 µm
tangential section				

AE 760.2

Macroscopic characterisation

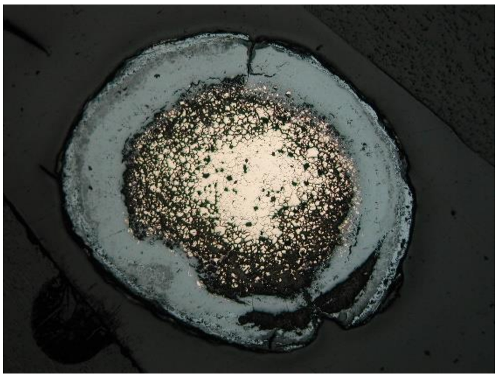
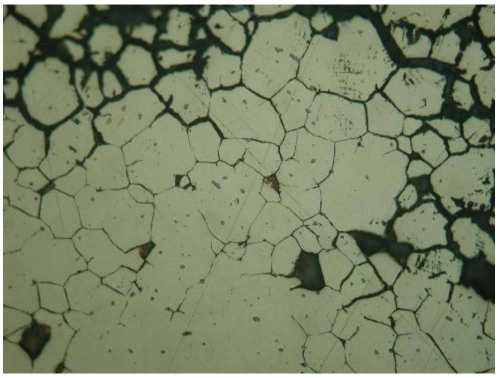
description	ring
EPMA no.	35
metal	bronze
Wgt	0.77 gr
Th	0.20 cm
L	3.00 cm
Corrosion	C

Simple, round cross-section ring, fragmented (Type Ia).

Metallography

The polished section revealed the round wire which consist of a granular microstructure with polygonal/angular grains often with strain lines and annealing twins, particularly closer to the surface. Minute, elongated sulphide and lead inclusions are visible too.

Corrosion: The sample's surface has been severely disrupted by destructive and growth corrosion layers and only a metal core is preserved. The latter is further affected by inter-/intra-granular corrosion revealing, thus, the microstructure and traces of the grains' mechanical stress.

Magn: 50x	Im.W.: 3.5 mm	Magn: 500x	Im.W.: 350 µm
			

AE 784.1

Macroscopic characterisation

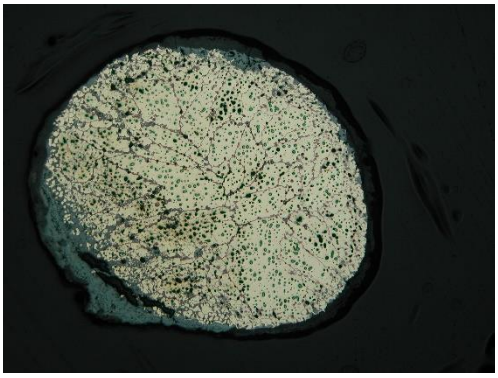
description	ring
EPMA no.	31
metal	bronze
Wgt	0.91 gr
Th	0.20 cm
L	2.35 cm
H	0.80 cm
Corrosion	B

Simple, round cross-section ring, fragmented (Type Ia).

Metallography

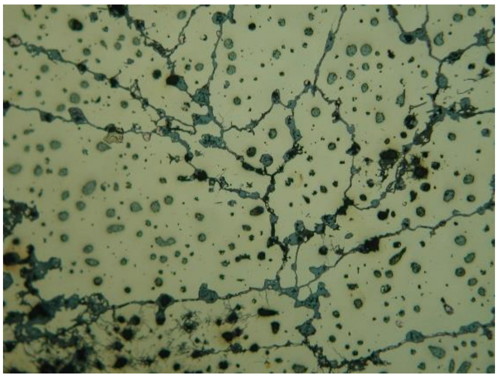
The polished section revealed an ovoid cross-section. The metal consists of large a-grains with several, large and round lead and sulphide inclusions, as well as large, round gas-holes. Closer to the surface, few polygonal/angular grains with strain lines and triple points are visible, possibly as the result of surface treatment in order to bring the wire to shape. Smaller, elongated inclusions are also visible.

Magn: 50x Im.W.: 3.5 mm

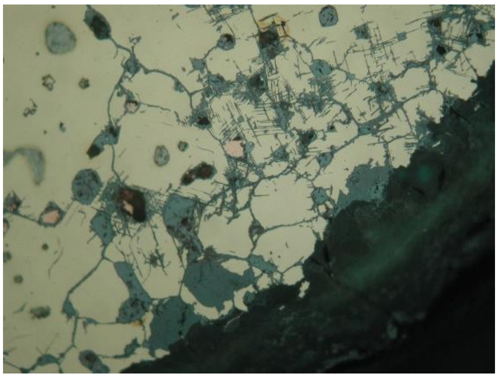


Corrosion: The ring's substrate is affected by corrosion, while the metal is affected throughout by inter-granular corrosion which has also attacked the lead inclusions. Thin patina is visible on the sample's surface. Some pure copper prills precipitate in between grain boundaries and in the gas-holes.

Magn: 200x Im.W.: 0.9 mm



Magn: 500x Im.W.: 350 µm



AE 796

Macroscopic characterisation

description	ring
EPMA no.	43
metal	bronze
Wgt	1.20 gr
Th	0.20 cm
Wdt	0.30 cm
D	2.25 cm
Corrosion	C

Simple, round cross-section ring, fragmented (Type Ia).

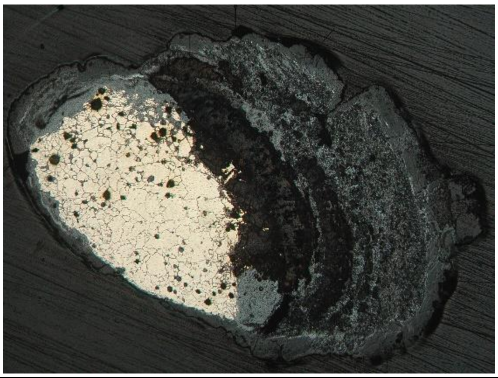
Metallography

The polished section revealed an ovoid shape which has been severely disrupted though by growth corrosion layers.

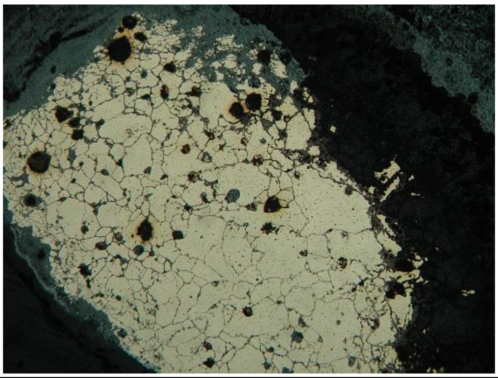
Sound metal consists of large α-grains, while closer to the surface limited recrystalisation takes place. The metal includes several lead and sulphide inclusions, as well as large, round gas-holes.

Corrosion: Growth corrosion layers precipitated on the ring's surface, while destructive corrosion has affected almost half of the section. In the sound metal, inter-granular corrosion has highlighted grain boundaries, the gas-holes and inclusions throughout.

Magn: 50x Im.W.: 3.5 mm



Magn: 100x Im.W.: 1.8 mm



AE 799

Macroscopic characterisation

description	ring
EPMA no.	62
metal	bronze
Wgt	1.93 gr
Th	0.09 cm
Wdt	1.05 cm
D	2.8 cm
Corrosion	C

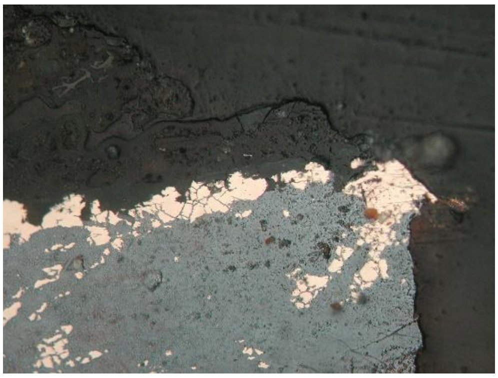
Fragmented ring (Type III) which comprises of thin metal sheet with traces of embossed decoration.

Metallography

Sample was cut from one of the open edges of the already fragmented metal sheet. Due to the sheet's thickness, corrosion products have affected the metal throughout, leaving only few specks of metal unaffected which revealed small, polygonal/angular metallic grains.

Corrosion: Destructive corrosion layers/products have not preserved the metal's original microstructure. Corrosion products include copper and tin oxides and chlorides.

Magn: 100x Im.W.: 1.8 mm Magn: 500x Im.W.: 350 μm



AE 810

Macroscopic characterisation

description ring

EPMA no. 11
metal bronze
Wgt 0.63 gr
Th 0.20 cm
L 2.20 cm
Corrosion C

Simple, round cross-section wire, fragmented (Type Ia).

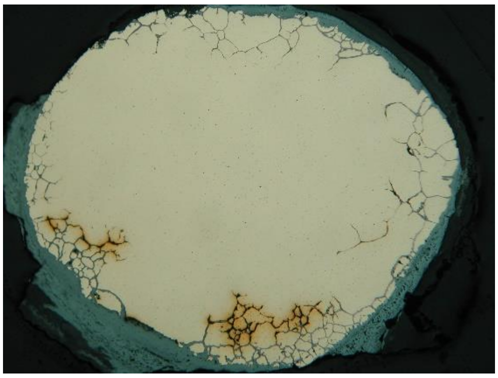
Metallography

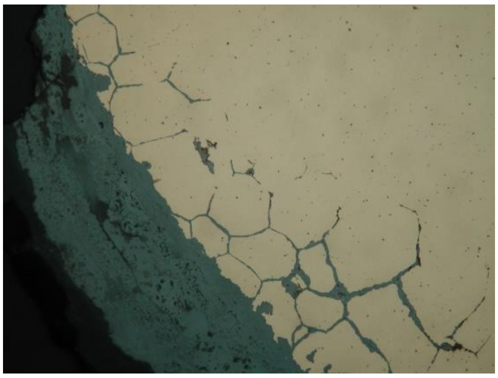
The polished section revealed a round/ovoid cross-section.

The sound metal revealed a structure of medium size polygonal/angular grains which often form triple points. In addition, several, minute sulphide and lead inclusions are visible.

Corrosion: Relatively well preserved with only the substrate and surface affected by corrosion products, where also the grains have been highlighted by inter-granular corrosion.

Magn: 100x	Im.W.: 1.8 mm	Magn: 500x	Im.W.: 350 µm





AE 827

Macroscopic characterisation

description	ring
EPMA no.	72
metal	bronze
Wgt	1.66 gr
Th	0.15 cm
Wdt	0.50 cm
L	2.60 cm
D	2.40 cm
Corrosion	C

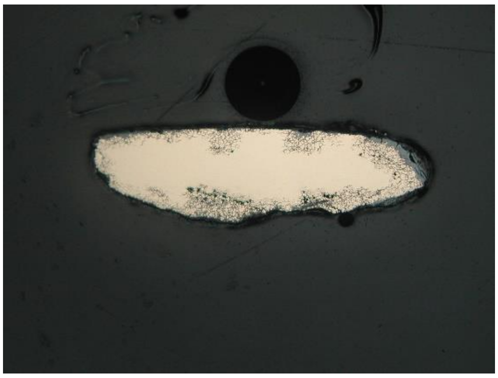
Fragment of ring with triangular/plano-convex cross-section (Type IIa/IIb).

Metallography

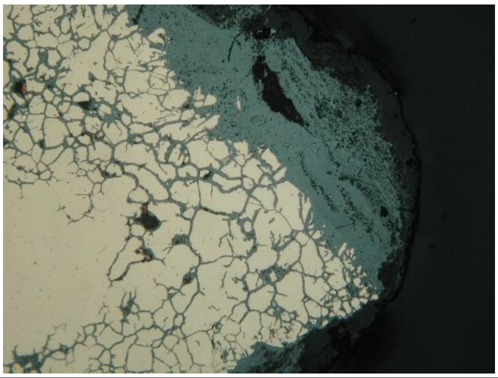
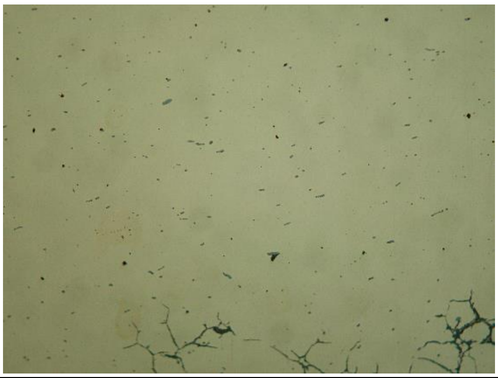
The ring's cross-section revealed a substantial metal core preserved with variable size, angular grains and with traces of strain lines, and elongated sulphide inclusions. Triple points are often visible. Grains closer to the surface have been more extensively worked than those in the sample's centre.

Corrosion: Inter-granular and limited intra-granular corrosion have highlighted the metal microstructure. Few pure copper prills precipitate on the sample's surface as the result of corrosion processes. Limited destructive corrosion has affected on side of the sample, while a thin patina layers covers the cross-section.

Magn: 25x Im.W.: 7 mm



Magn: 200x	Im.W.: 0.9 mm	Magn: 500x	Im.W.: 350 µm

AE 838

Macroscopic characterisation

description	ring
EPMA no.	30
metal	bronze
Wgt	1.44 gr
Th (min)	0.15 cm
Th (max)	0.21 cm
D	2.1
D of spiral	0.70 cm
Corrosion	C

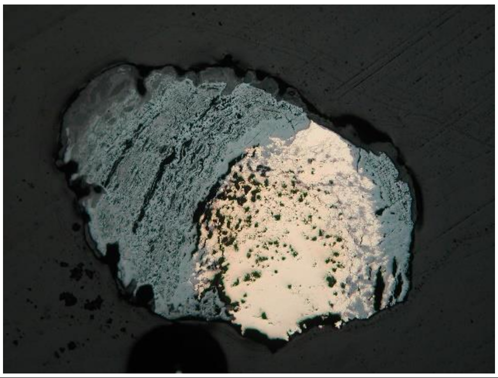
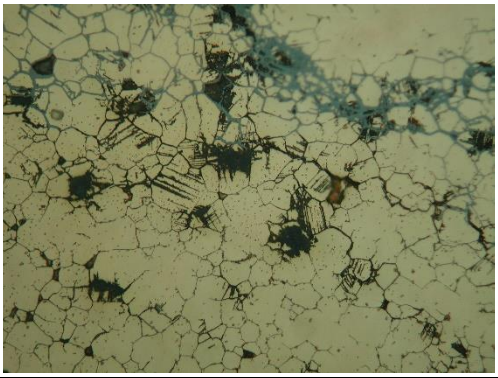
Simple, round-cross section ring with spiral decoration on its one end (Type Ib). See also AE 754.


Metallography

The polished section revealed the round wire which consist of a granular microstructure with polygonal/angular grains often with strain lines, particularly closer to the surface. Minute, elongated sulphide and lead inclusions are visible too.

Corrosion: The sample's surface has been severely disrupted by destructive and growth corrosion layers. Inter-/intra-granular corrosion has affected the metal throughout revealing the microstructure and traces of the grains' mechanical stress.

Magn: 50x	Im.W.: 3.5 mm	Magn: 500x	Im.W.: 350 µm

AE 856

Macroscopic characterisation

description	ring
EPMA no.	55
metal	bronze
Wgt	0.77 gr
Th	0.09 cm
Wdt	1.45 cm
L	1.70 cm
H	0.40 cm
Corrosion	B

Fragment of sheet ring (Type III). Ring comprises of a very thin folded metal sheet with traces of embossed decoration.

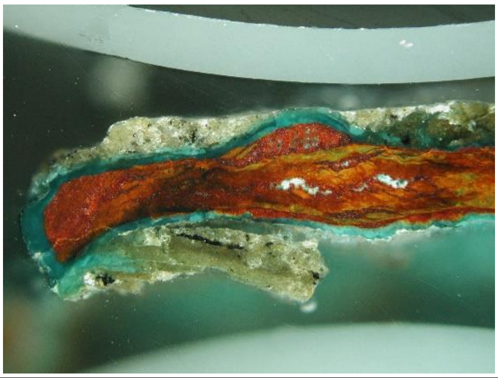
Metallography

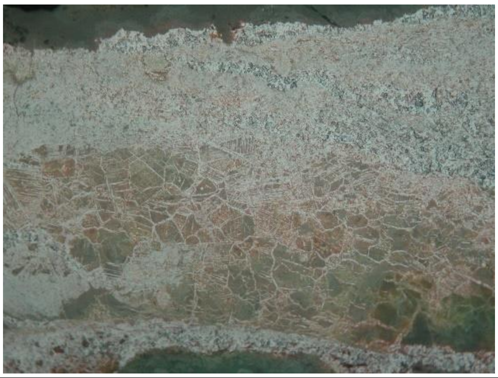
Sample cut from one of the edges of the fragmented metal sheet. A tangential and a cross section have been embedded in the resin block. Both samples proved to be corroded throughout due to the particularly small thickness of the metal sheet used, while only specks of metal have been preserved. However, corrosion products (copper and tin oxides) have replaced in places the original microstructure which revealed polygonal metallic grains with limited equiaxed structure. Growth corrosion products which have severely disrupted the sheet's original surface include cuprite, green copper salts and copper silicates.

Magn: 100x Im.W.: 1.8 mm

Magn: 500x Im.W.: 350 µm

cross section:





AE 899

Macroscopic characterisation

description	spiral
EPMA no.	53
metal	bronze
Wgt	0.76 cm
Th	0.10 cm
L	2.50 cm
D	0.35 cm
Corrosion	B

Fragment of spiral ring with very small diameter, probably used as a hair-attachment, with triangular/plano-convex cross-section.

Typology:
See also Vokotopoulou (1986, 1990).

Metallography

The sample was cut from one of the open ends of the spiral. The sample was embedded in the resin block so that its tangential section would be polished in order to expose a larger area of metal.

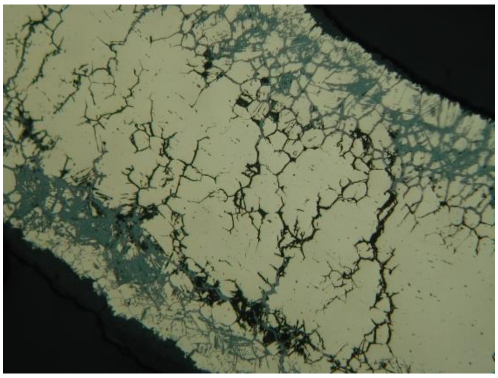
The sample showed a relatively good preservation with most of the metal preserved, while corrosion products have affected mainly the metals surface and have highlighted the metallic grain microstructure (inter-granular corrosion). Areas highlighted by corrosion productions also revealed the points where the metal had undergone mechanical stress during the forming of the spiral and the metal wire folding.

In the sound metal, few lead inclusion were found. Several sulphide inclusions were found which appeared particularly elongated, as well as they follow the direction of the metal wire as the result of the wire's hammering to shape.

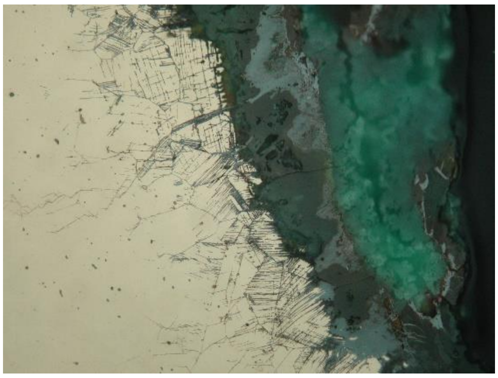
Tangential section

Magn: 25x Im.W.: 7 mm

Magn: 200x Im.W.: 0.9 mm



Magn: 500x Im.W.: 350 μm



AE 929

Macroscopic characterisation

description	ring
EPMA no.	40
metal	bronze
Wgt	0.93 gr
Th	0.15 cm
D	0.25 cm
Corrosion	B

Simple, round cross-section wire ring (Type Ia).

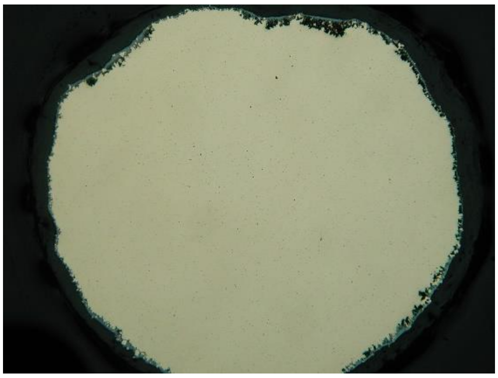
Metallography

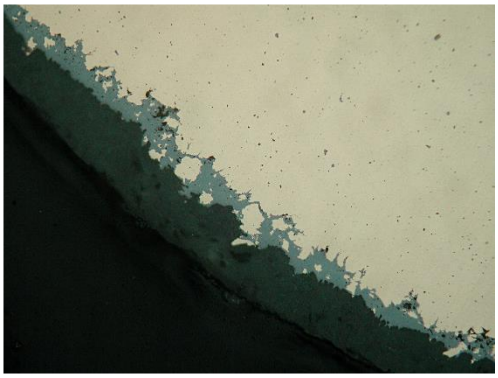
The polished section revealed an almost perfect round shape.

Due to the good state of its preservation, the microstructure is not particularly highlighted but still several small metal grains are visible in the ring's substrate. The metal includes several minute sulphide and lead inclusions.

Corrosion: Most of the metal core is intact. Only a thin layer of corrosion is noted in the substrate which is covered by a thin patina. Limited inter-granular corrosion in the substrate as well.

Magn: 100x	Im.W.: 1.8 mm	Magn: 500x	Im.W.: 350 µm





M 495.2

Macroscopic characterisation

description	metal sheet (fragment)
EPMA no.	38
metal	bronze
Wgt*	3.45
Th (min)*	0.11 cm
Th (max)*	0.12 cm
Wdt*	1.20 cm
L*	3.90 cm
H*	0.40 cm
Corrosion	B

Several metal sheet fragments of variable dimensions.

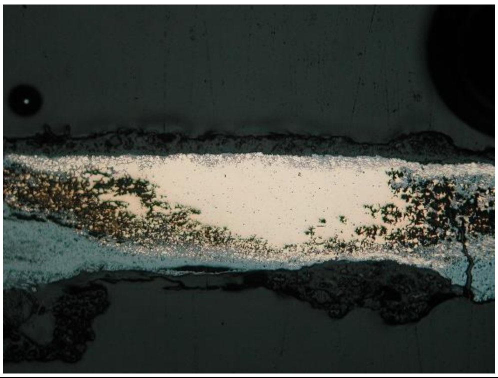
*Dimensions included here are for the individual fragment which has been sampled.

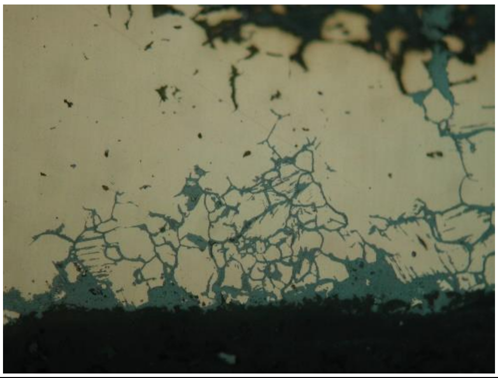
Metallography

The polished cross-section revealed a granular microstructure of small, angular, rather irregular grains with strain lines. Several elongated and angular sulphide inclusions are present, along with some lead ones.

Corrosion: Some destructive corrosion layers have formed in the substrate and thin growth layers have formed on the sample's surface. Inter- and intra-granular corrosion has highlighted the granular microstructure.

Magn: 50x Im.W.: 3.5 mm Magn: 500x Im.W.: 350 µm





M 798

Macroscopic characterisation

description	miniature vessel
EPMA no.	58
metal	leaded bronze
Wgt	43.96 gr
Th	0.10 cm
Wdt	3.90 cm
H	6.30 cm
Corrosion	A

Miniature metal vessel with a biconical body and long neck, and two decoration disks on the neck and rim, manufactured with the lost-was technique. The vessel must have been intended for decoration and exhibition as revealed by the ceramic core which was not removed making, thus, the vessel impossible to be filled with any liquid.

Metallography

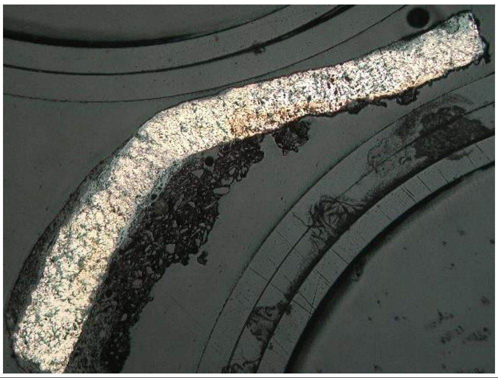
Sample was removed from the vessels fragmented rim. A cross section was polished in the resin block.

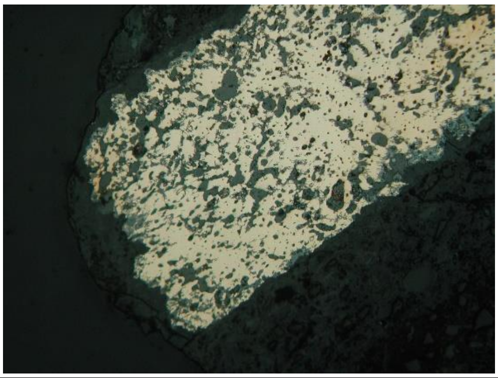
The sample revealed an as cast, dendritic structure in the metallic core, while closer to the surface and in the substrate strain lines were noted as the result of limited surface treatment that must have taken place when the vessel was first removed from the mould. Several lead and sulphide inclusions were visible.

Corrosion: Growth corrosion layers have affected more the one side of the sample, but its original surface has been preserved in its entirety. Metallic dendrites/structures have been highlighted by corrosion productions of copper and tin oxides. Some pure copper prills have precipitated as the result of corrosion processes. Lead prills have been mostly affected by corrosion products.

Magn: 50x Im.W.: 3.5 mm Magn: 200x Im.W.: 0.9 mm

cross section





M 801

Macroscopic characterisation

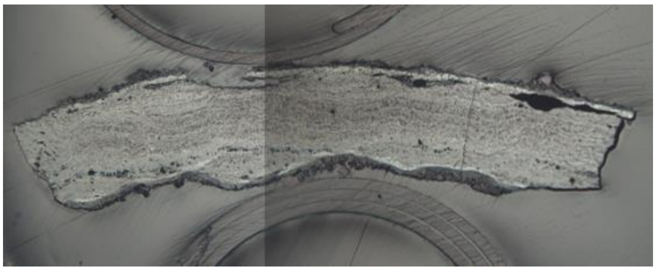
description	metal sheet
metal	corroded
Wgt	135.91 gr
Th (max)	0.30 cm
Th (min)	0.10 cm
Corrosion	D

Several metal sheet fragments. Some fragments are deformed and folded.

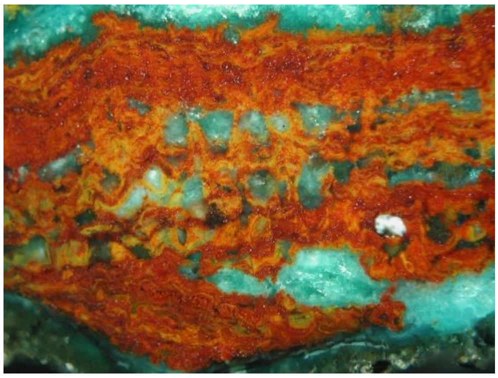
Metallography

The sample was cut from one of the metal sheet fragments. The embedded sample was corroded throughout. Destructive corrosion has substituted all the metal, but the surface on the sample's one side has been rather well preserved by the corrosion patina.

Magn: 25x Im.W.: 12 mm



Magn: 200x Im.W.: 0.9 mm, XPL



M 1217

Macroscopic characterisation

description	sheet
EPMA no.	80
metal	bronze
Wgt	380.00 gr
Th	0.10 cm
Wdt	variable
L	variable
Corrosion	C

A collection of pieces of fragmented metal sheets of various dimensions. All pieces are of bronze and most likely consisted parts of the same object, either a vessel or an armour piece.

Four different samples (M 1217, M 1217.1, M 1217.2 and M 1217.3) have been removed from these metal sheets. Their analyses confirmed that all fragments originated from a single object (or from objects with identical technology) as indicated both by their trace elements and their bulk chemical composition.

Metallography

Samples M 1217.1-3

Several samples have been taken from these metal sheet fragments. Quantitative examination of all samples confirmed that they all consist part of the same object.

Both cross- and tangential sections have been mounted in resin blocks.

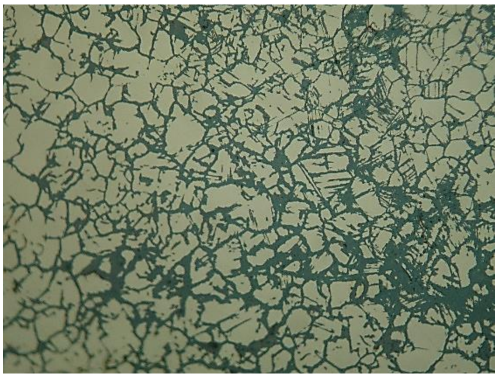
All samples revealed a granular microstructure with small, polygonal/angular grains often with strain lines and annealing twins, while few lead and several, elongated sulphide inclusions are present.

Corrosion: Variable corrosion features are present. Typically, a metal core is preserved with extended inter- and intra-granular corrosion and a surface patina. Sulphide inclusions have been preserved in the corrosion products.

tangential section

Magn: 50x Im.W.: 3.5 mm

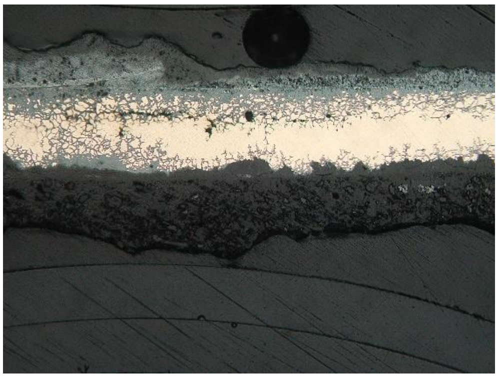
Magn: 500x Im.W.: 350 µm



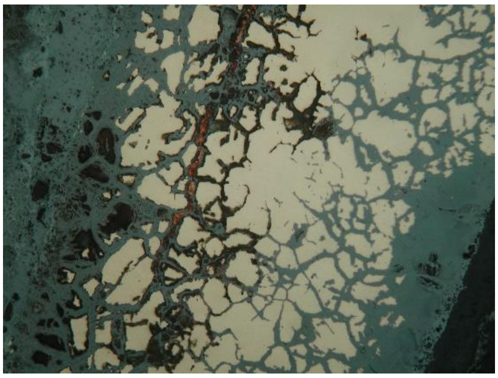
M 1217.1

EPMA no. 1

Magn: 200x Im.W.: 0.9 mm



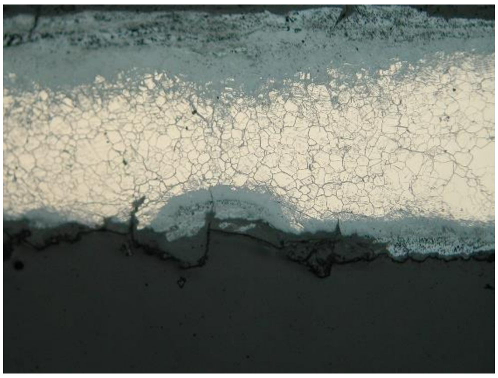
Magn: 500x Im.W.: 350 µm



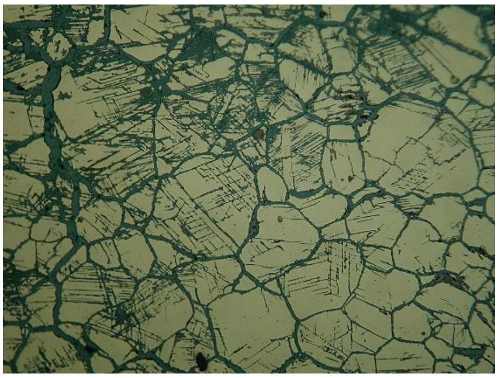
M 1217.2

EPMA no. 2

Magn: 100x Im.W.: 1.8 mm



Magn: 500x Im.W.: 350 µm

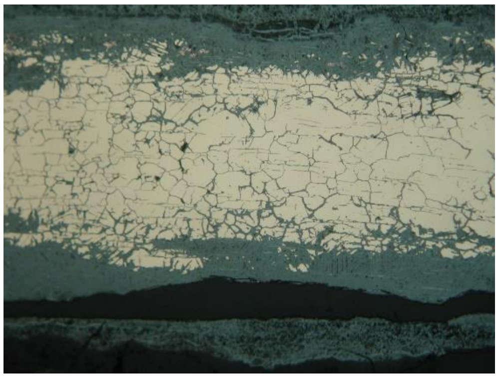


M 1217.3

EPMA no. 75

Magn: 500x Im.W.: 350 µm, XPL

Magn: 200x Im.W.: 0.9 m



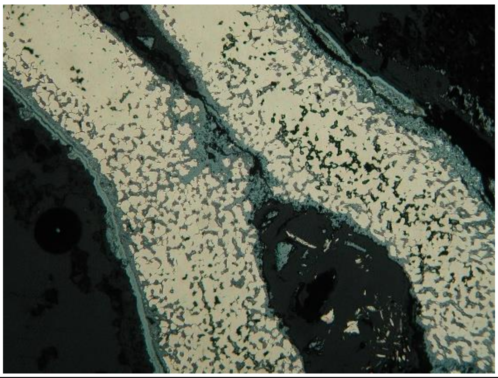
M 1217 C

Two thin metal sheets joint/cast together. The sample's cross-section revealed an as-cast structure with dendrites and few grains with triple points forming towards the sheets' surface. In place, the α and δ phases can be discerned. Small sulphide and lead inclusions are also visible.

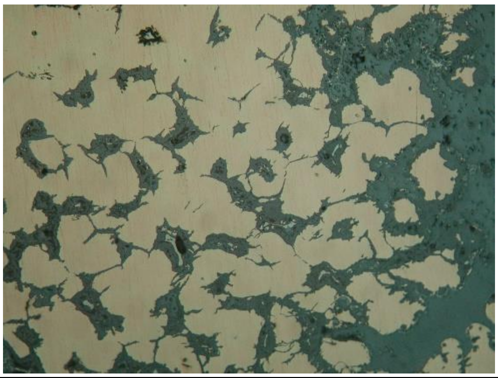
See also AE 606 for a similar microstructure.

Magn: 25x Im.W.: 15 mm

Magn: 100x Im.W.: 1.8 mm



Magn: 500x Im.W.: 350 µm, XPL



M 1314.1

Macroscopic characterisation

description	fibula
EPMA no.	20
metal	bronze
Wgt	7.47 gr
Th (min)	0.35 cm
Th (max)	0.50 cm
Wdt	1.85 cm
L	3.35 cm
H	1.50 cm
Corrosion	C

Bow from Epirotic fibula with a pair of side projections.

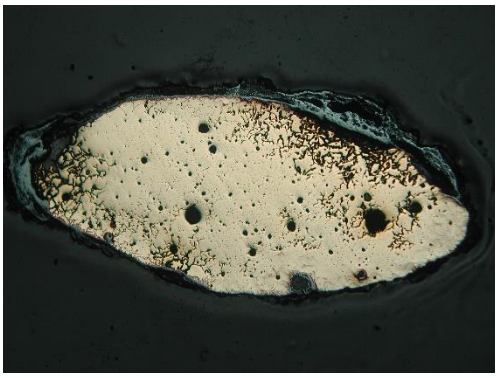
Typology:
Kilian (1975): Type K Ib or IIb
Blinkenberg (1926): Type V

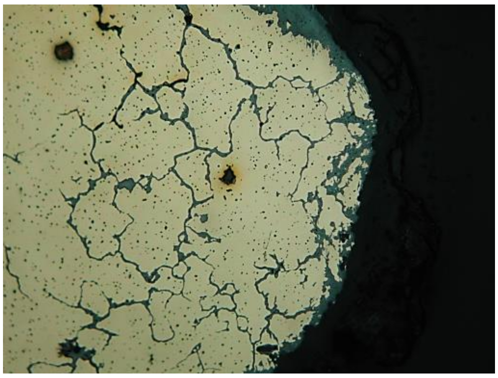
Metallography

The sample's cross-section revealed a microstructure of large α-grains with several, large gas-holes. Several small, round lead and sulphide inclusions are also visible.

Corrosion: The sample is relatively well preserved with very limited destructive corrosion in the substrate, and inter-granular corrosion which has highlighted the metal microstructure throughout the sample.

Magn: 50x　　Im.W.: 3.5 mm　　Magn: 200x　　Im.W.: 0.9 mm





M 1314.2

Macroscopic characterisation

description	fibula
EPMA no.	25
metal	bronze
Wgt	34.84 gr
Th (min)	0.45 cm
Th (max)	0.85 cm
Wdt	2.45 cm
L	4.65 cm
H	5.00 cm
Corrosion	B

Bow and catch-plate of Epirotic fibula with a pair of side projections.

Typology:
Kilian (1975): Type K Ib or IIb
Blinkenberg (1926): Type V

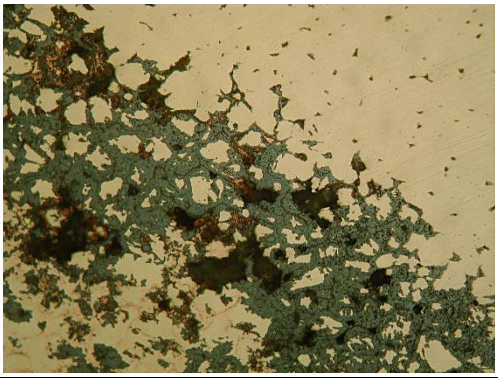
Metallography

The sample's tangential section revealed a granular structure with small, polygonal/angular grains and several angular, variable size lead and sulphide inclusions. Lead inclusions have been typically found in association with sulphide ones. Also, some coring is noted which could have taken place during the object's cooling.

Corrosion: A substantial core is preserved, while the substrate has been affected by inter-granular corrosion and re-deposited pure copper. Thin growth corrosion layers have precipitated on the sample's top (as in the 50x picture) side which have though preserved the sample's original surface.

Magn: 50x Im.W.: 3.5 mm | Magn: 500x Im.W.: 350 µm

tangential section

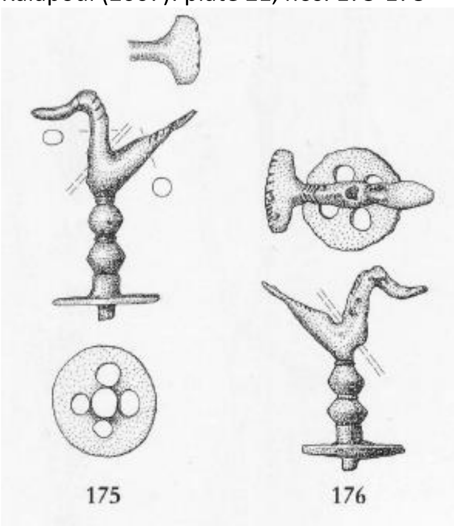


M 1652.1

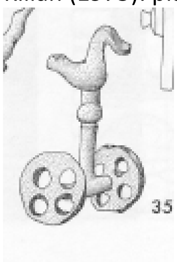
Macroscopic characterisation

Wheel disk possibly from Corinthian type pendant. See also M 2286 in Appendix III.2

Typology:
Kalapodi (2007): plate 21, nos. 175-178



Kilian (1975): plate 84, no.

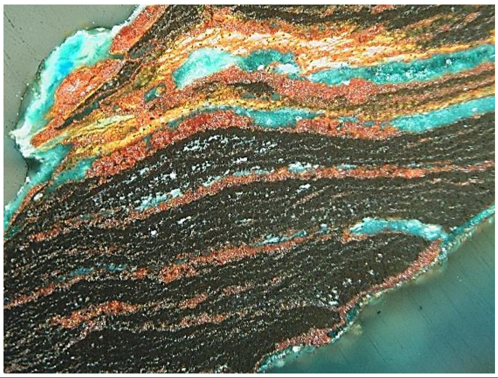


description	wheel disk/ bird pendant
EPMA no.	86
metal	bronze (corroded)
Wgt	11.52 gr
Th (min)	0.30 cm
Th (max)	1.15 cm
D	3.50 cm
Corrosion	D

Metallography

The sample has been corroded throughout and the metal has been substituted by destructive corrosion layers of copper and tin oxides and chlorides.

Magn: 25x Im.W.: 10 mm | Magn: 100x Im.W.: 1.8 mm, XPL



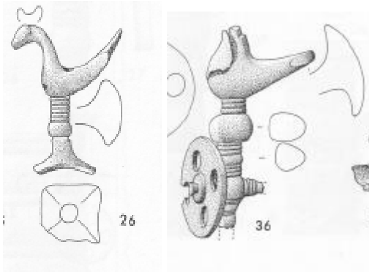
M 1683.2

Macroscopic characterisation

description	bird pendant
EPMA no.	85
metal	bronze (corroded)
Wgt	24.69 gr
Th (min)	0.40 cm
Wdt	3.10 cm
L	4.10 cm
H	3.10 cm
Corrosion	C/D

Bird pendant from Laconian workshop with large, flat tail and long neck, legs. Dated to the 7th century BC (after Voyatzis, 1990, 153-154).

Typology:
See M 1683.1
Also: Voyatzis (1990, 153; B 54, plate 89). The type has been also found in Olympia, Argos and Tegea
Kilian (1975): plate 84, nos. 26, 36

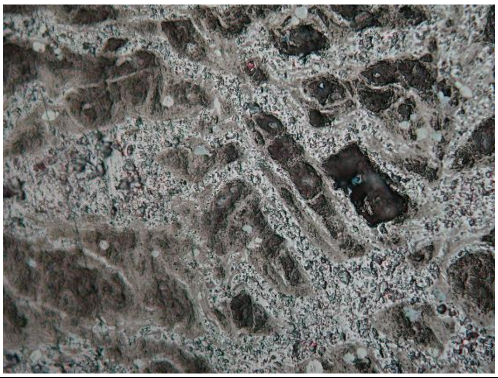


Metallography

The sample has been corroded throughout by destructive corrosion layers. However, traces of dendrites have been preserved.

Magn: 25x Im.W.: 10 mm

Magn: 500x Im.W.: 350 µm



M 1739.1

Macroscopic characterisation

description	fibula
EPMA no.	28
metal	bronze
Wgt	24.60 gr
Th (min)	0.40 cm
Th (max)	1.15 cm
Wdt	1.65 cm
L	5.90 cm
H	7.20 cm
Corrosion	C

Bow and arm preserved from fibula of Helladic type.

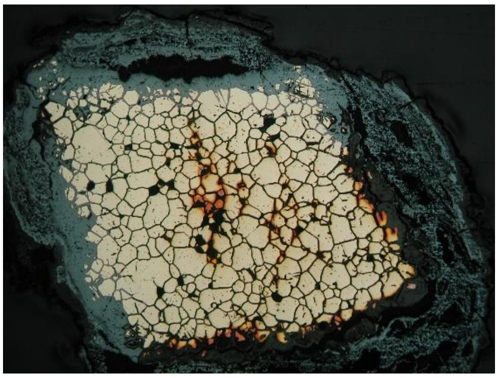
Typology:
Kilian (1975): Type D I
Blinkenberg (1926): Type VII

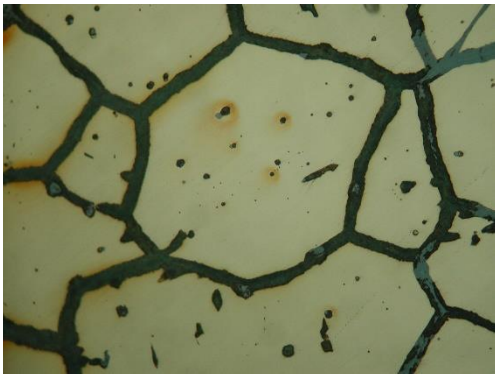
Metallography

Sample taken from end of fibula's arm whose cross section has been polished in the resin block. Sample has diamond shape cross section which reveals large metallic grains of angular and rather irregular shape as the result of hammering and recrystalisation during reheating. In the sound metal, round lead prills and sulphide inclusions are visible which tend to precipitate close to lead prills. The angular and elongated shape often seen in the lead/sulphide inclusions came as the result of cold-working of the fibula, i.e. hammering.

Corrosion: The surface is disrupted by thick growth corrosion layers of cuprite and copper salts, while metallic grains are disrupted by intergranular corrosion of copper and tin oxides. Limited intra-granular corrosion takes place. Selective corrosion within the metallic grains has substituted lead prills.

Magn: 50x Im.W.: 3.5 mm Magn: 500x Im.W.: 350 µm





M 1739.2

Macroscopic characterisation

description	fibula
EPMA no.	14
metal	bronze
Wgt	39.04 gr
Th (min)	0.70 cm
Th (max)	1.60 cm
Wdt	1.80 cm
L	4.20 cm
H	5.70 cm
Corrosion	C

Bow and arm preserved from fibula of Helladic type. The bow is decorated with three round globules, the middle one being larger than the side ones.

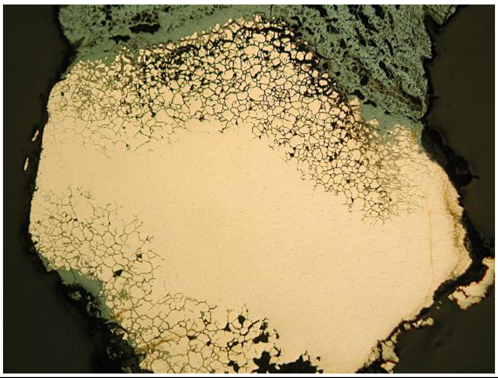
Typology:
Kilian (1975): Type E IIIb
Blinkenberg (1926): Type VII

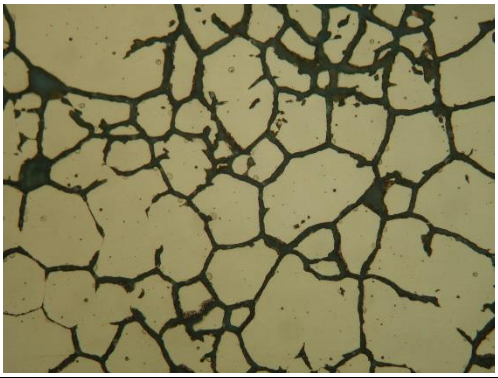
Metallography

Hexagonal cross-section sample. The metal microstructure consists of polygonal/angular grains, often with triple points and strain lines. Several small, angular sulphide and lead inclusions are visible.

Corrosion: Thick growth corrosion layers on one side of the sample, while its original surface has been preserved. Inter- and intra-granular corrosion have highlighted the metal microstructure closer to the surface leaving the core intact. In places, benign corrosion has preserved the original metal microstructure.

Magn: 50x	Im.W.: 3.5 mm	Magn: 500x	Im.W.: 350 µm





M 1739.3

Macroscopic characterisation

description	fibula
EPMA no.	13
metal	bronze
Wgt	5.48 gr
Th (min)	0.25 cm
Th (max)	0.95 cm
Wdt	0.90 cm
L	2.30 cm
H	3.80 cm
Corrosion	

Bow and arm of fibula of the Helladic type. Bow is decorated with a diamond shaped globule.

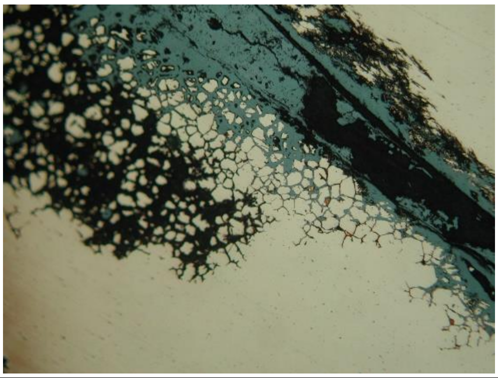
Typology:
Kilian (1975): Type E I
Blinkenberg (1926): Type VII

Metallography

Sample was removed from end of fibula's arm. Its cross-section revealed that the arm has been manufactured by putting together two pieces of metal which are clearly visible in the sample's polished section. They also seem to have particular microstructures, while the bottom wire's original surface outline has been preserved in the corrosion products. Metal grains are visible of polygonal/angular shape with limited strain lines. Sulphide and lead inclusions are also visible.

Corrosion: The sample's surface has been affected by thick grown corrosion layers, while corrosion products have also highlighted the two metal wires put together, as well as the metal granular microstructure.

Magn: 50x	Im.W.: 3.5 mm	Magn: 200x	Im.W.: 0.9 mm



M 1739.4

Macroscopic characterisation

description	fibula
EPMA no.	41
metal	bronze
Wgt	6.75 gr
Th (min)	0.45 cm
Th (max)	1.20 cm
Wdt	1.20 cm
L	3.40 cm
Corrosion	D

Bow fragment of fibula of the Helladic type. Bow is decorated with a diamond shaped globule.

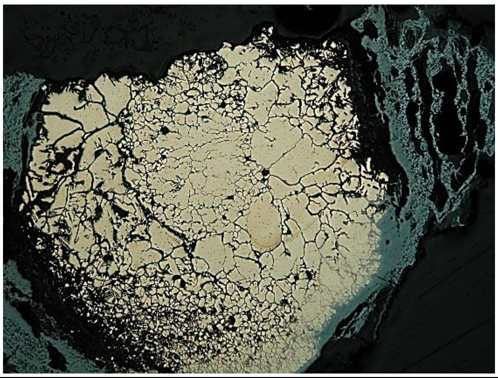
Typology:
Kilian (1975): Type E I
Blinkenberg (1926): Type VII

Metallography

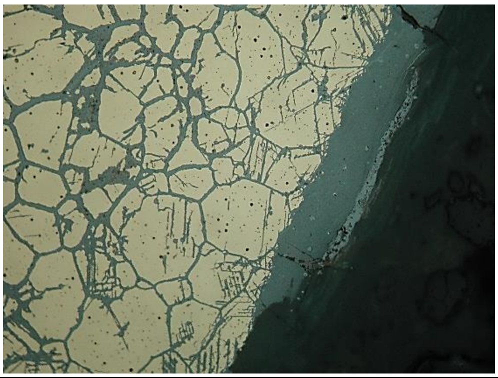
Sample with hexagonal cross-section. Inter- and intra-granular corrosion revealed polygonal/angular metal grains of several sizes, often with strain lines and annealing twins. Several sulphide and lead inclusions are also visible.

Corrosion: Growth corrosion layers have precipitated on the surface, but the original surface's shape has been preserved to an extent.

Magn: 50x Im.W.: 3.5 mm



Magn: 500x Im.W.: 350 µm



M 1815.2

Macroscopic characterisation

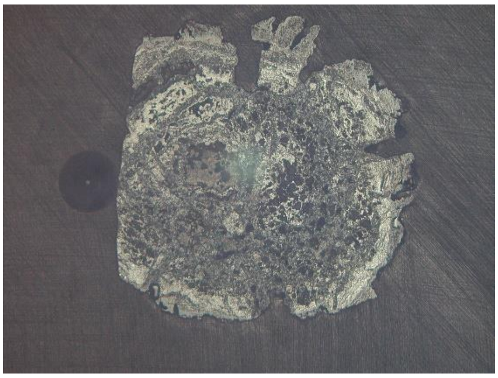
description	fibula
EPMA no.	34
metal	bronze (corroded)
Wgt	7.72 gr
Th (min)	0.45 cm
Th (max)	0.60 cm
L	5.50 cm
Corrosion	D

Fibula foot fragment which preserved part of the coil. Severely corroded.

Metallography

The sample's cross-section is corroded throughout with only specks of metal preserved. The sample is substituted by destructive corrosion products that were not possible to analyse. The sample's thickness has increased due to the action of corrosion which as caused the metal to swell. The metal core has been substituted by chlorides as also seen in other samples too.

Magn: 25x Im.W.: 10 mm Magn: 50x Im.W.: 3.5 mm, XPL



M 1844

Macroscopic characterisation

description	metal sheet/ vessel rim (?)
EPMA no.	81
metal	bronze
Wgt	7.42 gr
Th (min)	0.09 cm
Th (max)	0.20 cm
Wdt	0.95 cm
D	6.00cm
Corrosion	C

Folded metal sheet. Possibly part of vessel rim.

Metallography

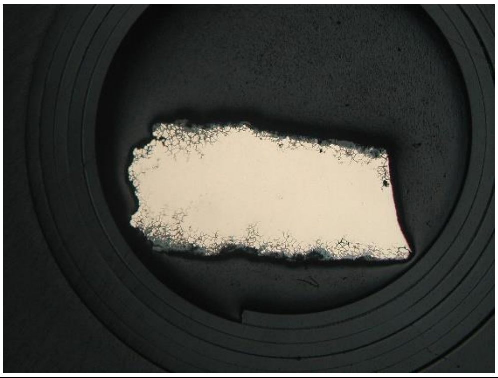
Sample was cut from one of the metal sheets open ends. A tangential section of the sample was embedded in the resin block.

A substantial metallic core was preserved in the sample. Relatively large metallic grains were noted. Grains were of polygonal shape often forming triple points (equiaxed structure). Inter- and intra-granular corrosion close to the surface revealed stressed grains with strain lines and slip planes. Very few, small inclusions were found in the sound metal, either sulphide or lead inclusions.

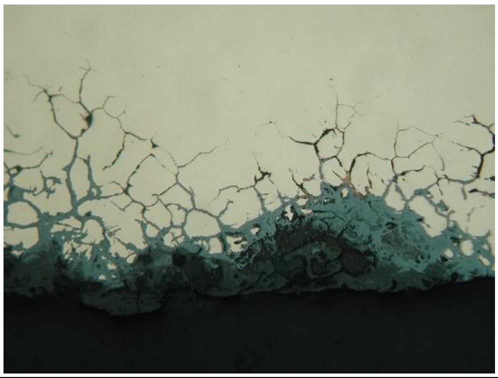
Corrosion: A layer of corrosion products precipitates on the sample's surface. Limited inter-granular corrosion takes place mostly on the substrate layers and not in the metal core. Cuprite and green copper salts precipitate as surface corrosion layers.

Tangential section

Magn: 25x Im.W.: 7 mm



Magn: 200x Im.W.: 0.9 mm



M 2117.2

Macroscopic characterisation

Description	fibula
Wgt (gr)*	5.20 gr
bow:	
metal	bronze
L (max)	4.90 cm
H (max)	3.00 cm
Th.	0.30 cm
Corrosion	C

Simple Thessalian, round cross-section bow fibula.

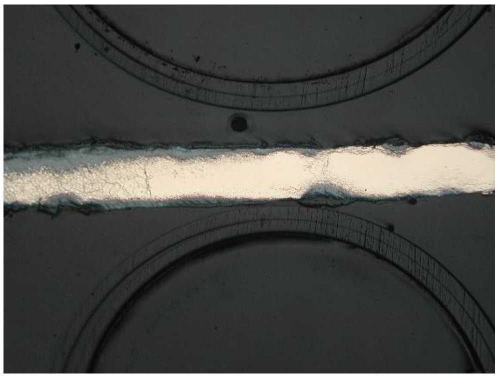
*Weight measurement includes both the fibula bow and foot.

Metallography

The sample was cut from the fibula's catch-plate. Its microstructure consist of small, polygonal/angular grains with triple points, strain lines and annealing twins.

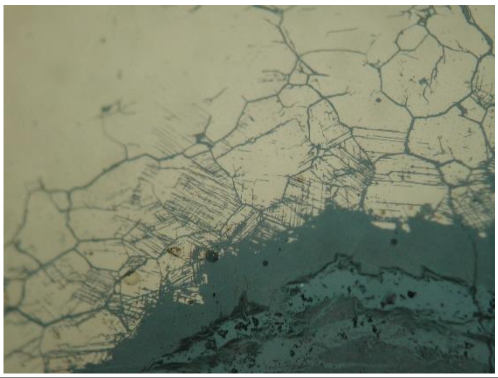
Corrosion: Relatively well preserved sample with limited destructive corrosion in the substrate, surface patina, and inter-/intra-granular corrosion which highlights the microstructure.

Magn: 25x Im.W.: 7 mm



Magn: 200x Im.W.: 0.9 mm

Magn: 500x Im.W.: 350 μm



M 2233

Macroscopic characterisation

description ring

EPMA no. 39

metal bronze

Wgt 3.71 gr

Th (min) 0.15 cm

Th (max) 0.40 cm

L 4.60 cm

H 1.70 cm

D (ring) 2.00 cm

Corrosion C

Complete, miniature Epirotic fibula with a pair of side projections on the bow and elongated catch-plate with attached ring of Type Ia from simple, round cross-section wire.

The sample was cut from the ring which is fragmented (it has been put together for the picture).

Typology (fibula):
Kilian (1975): Type K Ia
Blinkenberg (1926): Type V

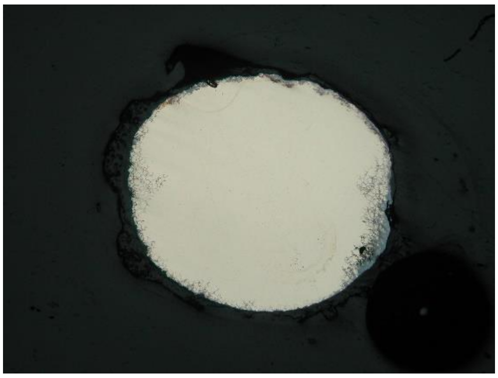
Metallography

The ring's cross-section revealed an almost perfect round shape.

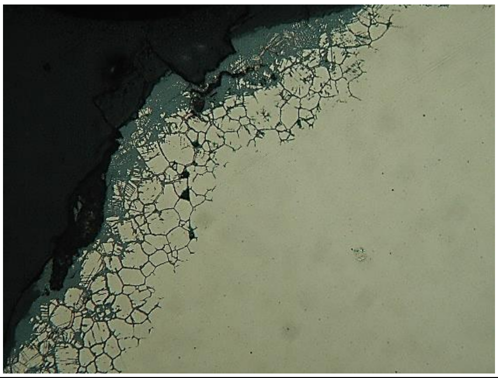
The metal consists of small, polygonal/ angular metal grains often with triple points. Grains include strain lines and in places annealing twins. Several sulphide and lead inclusions are visible.

Corrosion: Very good preservation state with only a thin patina on the surface, and inter- and intra-granular corrosion. Strips of pure copper have precipitated on the sample's surface.

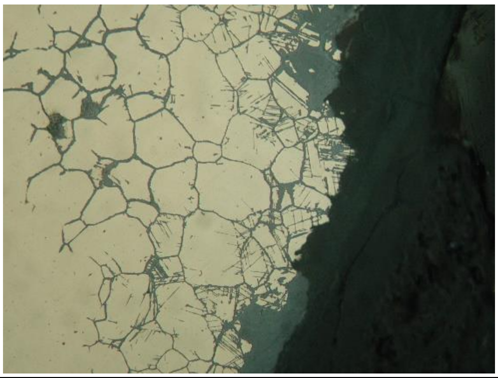
Magn: 50x Im.W.: 3.5 mm



Magn: 200x Im.W.: 0.9 mm



Magn: 500x Im.W.: 350 µm



M 2265

Macroscopic characterisation

description	fibula
EPMA no.	87
metal	bronze (corroded)
Wgt	7.22 gr
Th (min)	0.15 cm
Th (max)	0.25 cm
Wdt	3.00 cm
L	5.70 cm
H	0.90 cm
Corrosion	B

Fragment of Attic-boeotian fibula with sheet, leaf bow.

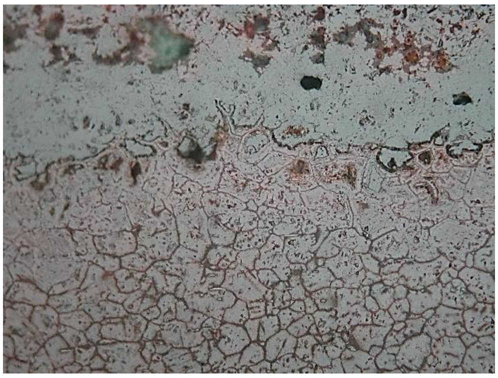
Typology:
Kilian (1975): Type B II
Blinkenberg (1926): Type VIII

Metallography

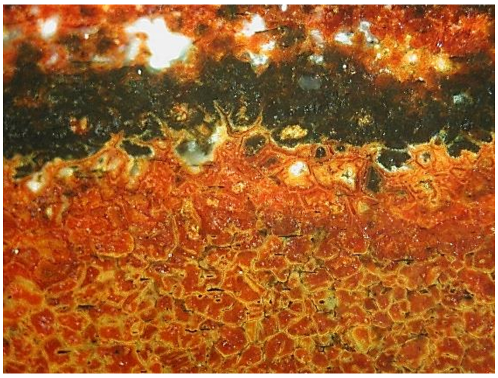
Fibula's cross-section has been corroded throughout. However, benign corrosion has preserved the metal's original granular microstructure of small, polygonal/angular grains with triple points. In addition, the sample's original surface has been preserved in the corrosion layers. Some pure copper has been re-deposited as the result of corrosion. Thick layers of growth corrosion have accumulated on the sample's surface.

Magn: 50x Im.W.: 3.5 mm, XPL

Magn: 500x Im.W.: 350 µm



Magn: 500x Im.W.: 350 µm, XPL



M 2276

Macroscopic characterisation

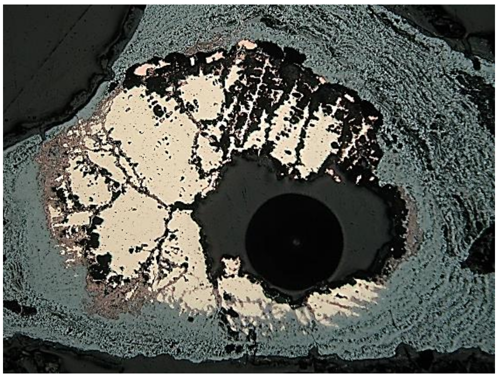
description	bird pendant	Bird pendant severely corroded, with suspension hole at the head.
EPMA no.	24	
metal	bronze	See also M 2284 in Appendix III.2.
Wgt	8.91 gr	
Th (min)	0.20 cm	Typology:
Th (max)	1.05 cm	Kilian (1975): plate 84, no. 32
L	1.80 cm	
H	3.50 cm	
Corrosion	C	

Metallography

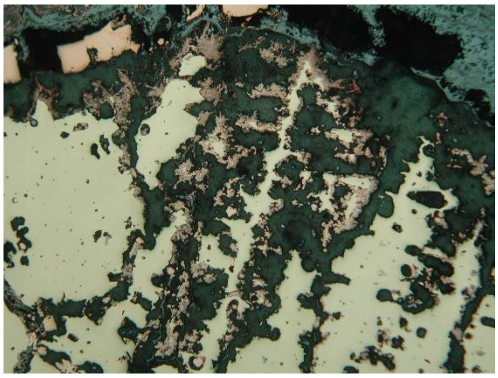
The sample’s cross-section revealed a large gas-hole in the middle of the metal. The metal’s microstructure showed traces of long and thin dendrites and large α-grains as the result of casting the pendant. Typically small lead and sulphide inclusions of irregular shapes are also visible.

Corrosion: The sample’s original surface has been severely disrupted by destructive and growth corrosion layers. Corrosion products have also highlighted the metal microstructure (dendrites, α-grains). Also, some pure copper has been re-deposited in between the grain/dendrite boundaries.

Magn: 50x Im.W.: 3.5 mm



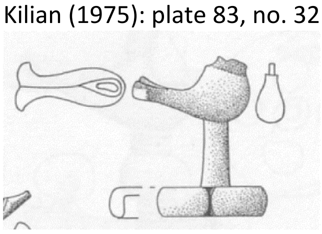
Magn: 200x Im.W.: 0.9 mm



M 2277

Macroscopic characterisation

description	bird pendant	Fragment of bird pendant.
EPMA no.	16	Typology:
metal	bronze	Kilian (1975): plate 83, no. 32
Wgt	8.03 gr	
Wdt	1.00 cm	
L	2.00 cm	
H	2.20 cm	
Corrosion	D	



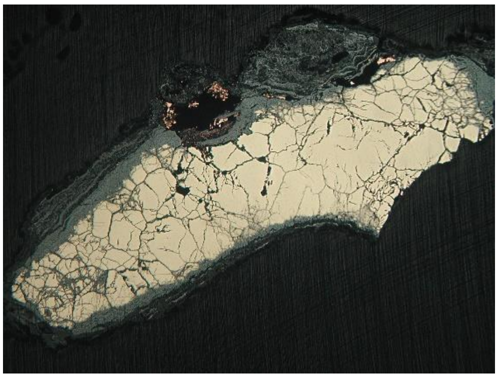
Metallography

tangential section

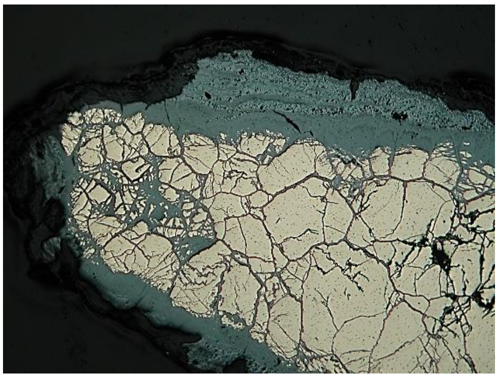
The sample's tangential section revealed large angular grains with strain lines. Small sulphide and lead inclusions are also visible. Some grains despite their large size provided evidence of mechanical stress. Several cracks are also visible in the sample.

Corrosion: The sample has been affected throughout by inter- and intra-granular corrosion. Limited destructive corrosion has affected the substrate, while growth layers are visible on the sample's one side.

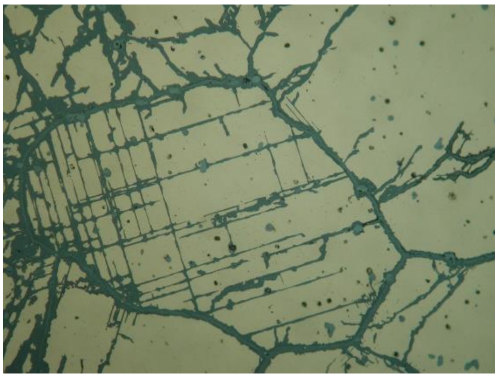
Magn: 25x Im.W.: 7 mm



Magn: 50x Im.W.: 3.5 mm



Magn: 500x Im.W.: 350 µm



M 3234

Macroscopic characterisation

description	arm band (?)
EPMA no.	26
metal	bronze
Wgt	23.51 gr
Th	0.30 cm
Wdt	0.60 cm
L	10.00 cm
D	6.60 cm
Corrosion	C

Long piece of folded metal wire with a plano-convex/triangular cross section. Possibly a deformed arm band or large ring.

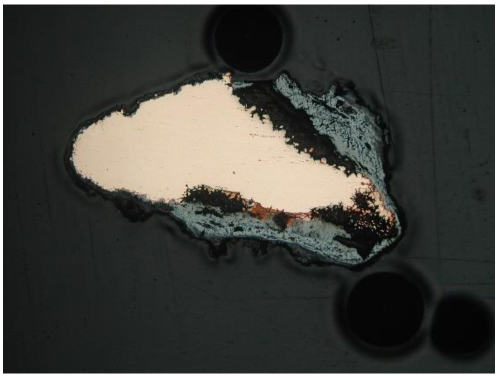
Metallography

A sample was removed from the object's one open end and its cross section was polished in the resin block. The triangular cross section revealed few metallic grains on the sample's substrate which have been highlighted by inter-granular corrosion. In the metal, few lead and sulphide inclusions have been found with no signs of severe deformation, but rather rounded edges.

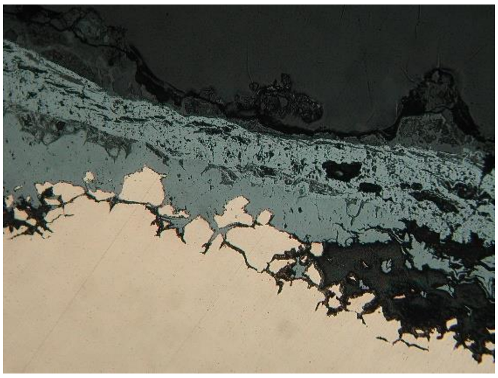
Chemical etching would be needed for a more detailed examination of the sample's microstructure.

Corrosion: Growth corrosion layers have affected two of the three sides of the cross section, while a thin patina layer covers the rest of the sample. Limited pseudomorphic replacement of the metallic grain microstructure by copper and tin oxides also takes place.

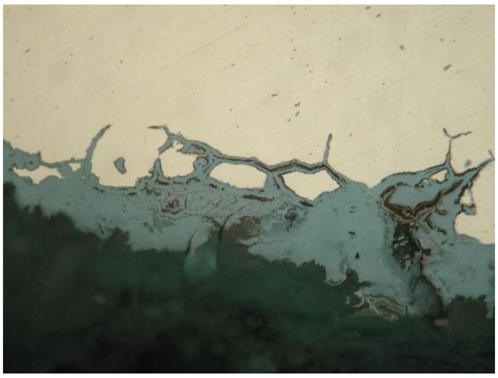
Magn: 25x Im.W.: 7 mm



Magn: 100x Im.W.: 1.8 mm



Magn: 500x Im.W.: 350 µm



M 3367.1

Macroscopic characterisation

description	fibula
EPMA no.	8
metal	bronze
Wgt	2.66 gr
Th (min)	0.20 cm
Th (max)	0.55 cm
Wdt	0.5 cm
L	2.25 cm
H	1.80 cm
Corrosion	C

Bow from miniature Epirotic fibula with simple bow.

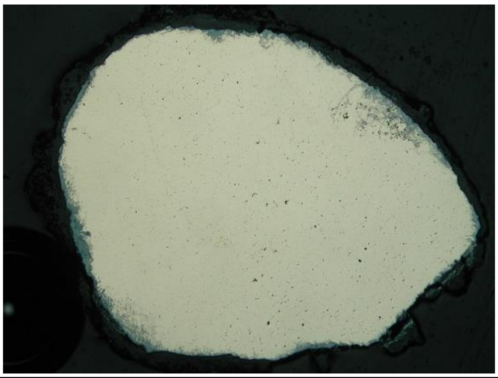
Typology:
Kilian (1975): Type K IIa
Blinkenberg (1926): Type V

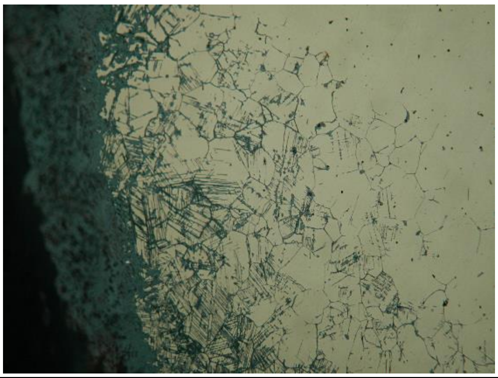
Metallography

The cross-section revealed a round/ovoid shape. Metal microstructure revealed small, polygonal grains with strain lines and slip planes and several angular sulphide and lead inclusions.

Corrosion: Only limited surface patina and inter-/intra-granular corrosion in the substrate. Otherwise, very good state of preservation with most of the metal being intact.

Magn: 50x	Im.W.: 3.5 mm	Magn: 500x	Im.W.: 350 µm





M 3367.2

Macroscopic characterisation

description	fibula
EPMA no.	10
metal	bronze
Wgt	2.75 gr
Th (min)	0.15 cm
Th (max)	0.45 cm
Wdt	0.55 cm
L	2.90 cm
H	2.40 cm
Corrosion	B

Bow from miniature Epirotic fibula with simple bow.

Typology:
Kilian (1975): Type K Ia or IIa
Blinkenberg (1926): Type V

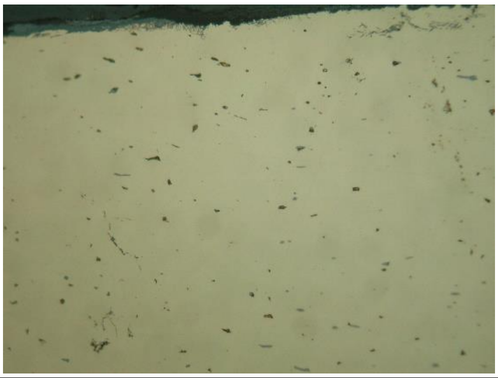
Metallography

The sample's tangential section revealed a microstructure of small angular grains with several strain lines. Sulphide and lead inclusions are angular, elongated and often square/rectangular.

Corrosion: Good state of preservation with limited surface patina and inter-/intra-granular corrosion in the substrate.

Magn: 50x	Im.W.: 3.5 mm	Magn: 500x	Im.W.: 350 µm

tangential section



Mμ 8100/2075

Macroscopic characterisation

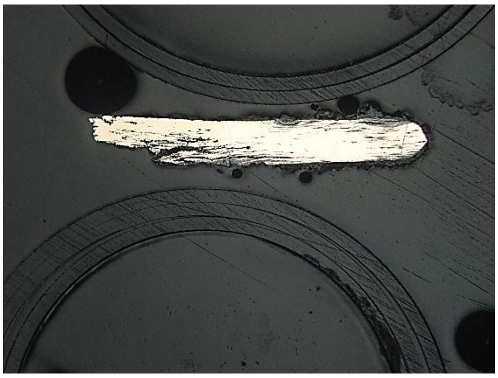
description	metal sheet	
EPMA no.	78	
metal	bronze	
Wgt	13.22 cm	Object from thin metal sheet. Possibly a wooden box decoration.
Th	0.10 cm	
Wdt	4.30 cm	
L	8.50 cm	
Corrosion	C	

Metallography

The sample's cross-section revealed a microstructure of small, polygonal/angular metal grains with several strain lines and annealing twins. Few minute lead and sulphide inclusions are also visible.

Corrosion: The metal sheet is relatively well preserved, retaining a substantial metal core. Limited destructive corrosion has taken place in the substrate, while inter- and intra-granular corrosion have highlighted significantly the metal microstructure.

Magn: 25x Im.W.: 7 mm



Magn: 500x Im.W.: 350 μm

III.2 Non-invasive sampling (pXRF)

AE 20

Macroscopic characterisation

Description	biconical pendant
pXRF no.	VO069
metal	bronze
Weight (gr)	14.54 gr
L (max)	2.70 cm
Th. (min)	0.85 cm
Th. (max)	1.65 cm
Corrosion	A

Biconical pendant/bead with a tubular suspension hole.

AE 26

Macroscopic characterisation

Description	ring
pXRF no.	VO187
metal	leaded bronze
Weight (gr)	1.93 cm
D	2.25 cm
Th. (min)	0.20 cm
Th. (max)	0.25 cm
Corrosion	A

Simple round cross section wire ring (Type Ia) with closed ends.

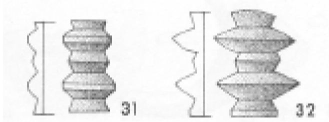
AE 35

Macroscopic characterisation

Description	biconical pendant
pXRF no.	VO198
metal	bronze
Weight (gr)	16.22 gr
L (max)	2.15 cm
D (min)	1.35 cm
D (max)	1.70 cm
Corrosion	A

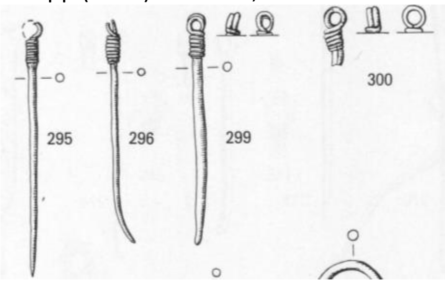
Biconical pendant/bead with tubular suspension hole. The pendant is decorated with a sequence of biconical elements separated by a decorative disk.

Typology:
Kilian (1975): plate 77, nos. 31-32



AE 47

Macroscopic characterisation

Description	pin	Pin with decoration at the head where a thin wire has been wound around the pin's body which is typically thicker. The pin's end has been bent. Typology: Philipp (1981): Plate 36, nos. 295-303	
pXRF no.	VO133		
metal	bronze		
Weight (gr)	2.22 gr		
L (max)	5.35 cm		
Th. (min)	0.10 cm		
Th. (max)	0.45 cm	Isthmia (1998): plate 35, no. 189 (IM 970)	
Corrosion	A		

AE 86/BE 45749

Macroscopic characterisation

Description	pin	Pin or possibly a tool whose end forms a round, elongated drop, and with small decoration at the head.	
pXRF no.	VO135		
metal	zinc-rich unalloyed copper		
Weight (gr)	3.13 gr		
L (max)	9.10 cm		
Th. (min)	0.20 cm		
Th. (max)	0.35 cm		
Corrosion	A		

AE 94

Macroscopic characterisation

Description	ring	Ring with round, thick cross section and closed ends (Type IVa).	
pXRF no.	VO134		
metal	bronze		
Weight (gr)	13.19 gr		
D	3.30 cm		
Th. (min)	0.40 cm		
Th. (max)	0.50 cm		
Corrosion	B		

AE 95

Macroscopic characterisation

Description	ring	
pXRF no.	VO046	Ring with thick, round cross section, closed ends, and five projections (Type IVb). The projections have an inverted conical shape.
metal	leaded bronze	
D	3.50 cm	
Th. (min)	0.30 cm	
Th. (max)	0.40 cm	
Corrosion	A	

AE 106

Macroscopic characterisation

Description	ring	Metal sheet ring with folded ends and embossed linear decoration (Type III).
pXRF no.	VO131	
metal	bronze	
Weight (gr)	7.54 gr	
H	1.05 cm	
D	2.30 cm	
Th. (max)	0.15 cm	
Corrosion	A	

AE 109

Macroscopic characterisation

Description	ring	
pXRF no.	VO129	Ring with thick, round cross section (Type IVa). The ring is thinner on one side while the thickness may vary during its whole length.
metal	leaded bronze	
Weight (gr)	3.75 gr	
D	2.3 cm	
Th. (min)	0.30 cm	
Th. (max)	0.40 cm	
Corrosion	B	

AE 111

Macroscopic characterisation

Description	ring
pXRF no.	VO132
metal	bronze
Weight (gr)	4.58 gr
D	2.20 cm
H (max)	0.60 cm
Th. (min)	0.10 cm
Th. (max)	0.35 cm
Corrosion	B

Round triangular section ring with ends visibly touching (Type IIa).

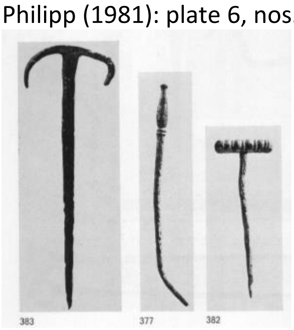
AE 116

Macroscopic characterisation

Description	object fragment
pXRF no.	VO216
metal	unalloyed copper
Weight (gr)	1.33 gr
L (max)	3.90 cm
Width	1.20 cm
Th. (min)	0.10 cm
Th. (max)	0.40 cm
Corrosion	A

T-shaped fragment from object. Possibly, fragment from top part of pin (?) based on similar finds from Olympia or other metal fixtures based on find from Isthmia.

Typology:
Kilian (1975): plate 94, no. 1
Kalapodi (2007): pate 59, nos. 2137-40
Philipp (1981): plate 6, nos. 382-383



Isthmia (1998): plate 80, no. IM 3209
See also AE 487.

AE 118

Macroscopic characterisation

Description	ring
pXRF no.	VO205
metal	leaded bronze
Weight (gr)	1.51 gr
Width	0.80 cm
D	2.20 cm
Th. (max)	0.05 cm
Corrosion	A

Metal sheet ring with open, folded ends and incised decoration forming a zig-zig pattern of pyramids and inverted triangles (Type III).

Decoration:

Typology:
Kilian (1975): plate 70. no. 70

AE 120

Macroscopic characterisation

Description	nail
pXRF no.	VO101
metal	leaded bronze
Weight (gr)	34.59
L (max)	6.00 cm
nail head:	
H	1.10 cm
D	5.10 cm
Th.	0.20 cm
Corrosion	B

Nail with iron rod and copper-based head. Analyses was conducted on the nail's head which forms a mushroom-shaped cap (see also AE 203 below).

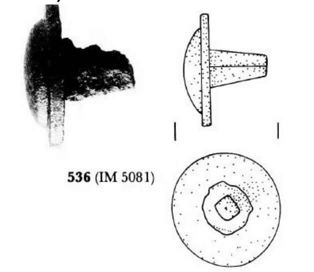
AE 148

Macroscopic characterisation

Description	nail
pXRF no.	VO045
metal	leaded bronze
Weight (gr)	6.28 gr
L (max)	3.35 cm
D	2.00 cm
Th. (min)	0.30 cm
Th. (max)	0.45 cm
Corrosion	A

Copper based head with a square cross section rod and plano-convex head with two levels. Nail's head base is flat and top part is round.

Typology:
Isthmia (1998): plate 84, no. 536 (IM 5081)



AE 153

Macroscopic characterisation

Description	decorative ornament
pXRF no.	VO161
metal	leaded bronze
Weight (gr)	256.37 gr
L (max)	13.40 cm
Width	8.70 cm
Th. (min)	0.06 cm
Th. (max)	1.00 cm
Corrosion	A

Decorative ornament representing floral pattern often used as an architectural element.

AE 261

Macroscopic characterisation

Description	ring
pXRF no.	VO175
metal	leaded bronze
Weight (gr)	1.07 gr
D	2.00 cm
Th. (max)	0.20 cm
Corrosion	A

Thin, round cross section wire ring with open ends which overlap (Type Ia).

AE 203

Macroscopic characterisation

Description	nail (head)
pXRF no.	VO194
metal	leaded bronze
Weight (gr)	43.94 gr
nail head:	
H (max)	1.20 cm
D	5.10 cm
Th.	0.20 cm
Corrosion	A

Nail with round iron rod and copper-based head/cap (see also AE 120). Analyses conducted on the nail's head.

AE 245

Macroscopic characterisation

Description	ring
pXRF no.	VO209
metal	leaded bronze
Weight (gr)	1.66 gr
D (exterior)	1.4 cm
Th. (min)	0.20 cm
Th. (max)	0.30 cm
Corrosion	A

Ring with round, thick cross section (Type IVa).

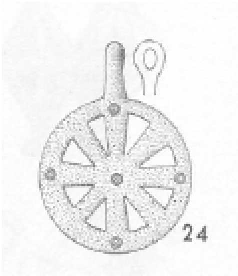
AE 268

Macroscopic characterisation

Description	wheel disk pendant
pXRF no.	VO174
metal	bronze
Weight (gr)	3.56 gr
L (max)	3.20 cm
Width	0.50 cm
Th. (min)	0.10 cm
D	2.50 cm
Corrosion	B

Wheel disk pendant with suspension hole and six radii forming six triangles.

Typology:
Kilian (1975): plate 79, no. 24



AE 275

Macroscopic characterisation

Description	fibula
pXRF no.	VO006
metal	bronze
Weight (gr)	7.97 gr
L (max)	3.70 cm
H (max)	2.60 cm
Width	0.70 cm
Th. (min)	0.20 cm
Th. (max)	0.70 cm
Corrosion	A

Thessalian fibula bow with triangular shape and decorative projection on the top.

Typology:
Kalapodi (2007): plate 21, no. 171
Kilian (1975): type C XI
BlinkenbergL (1926): Type VI

AE 279

Macroscopic characterisation

Description	vessel fragment (?)
pXRF no.	VO186
metal	leaded bronze
Weight (gr)	9.28 gr
L (max)	4.15 cm
H (max)	1.15 cm
Width	1.15 cm
Th. (min)	0.25 cm
Th. (max)	0.30 cm
Corrosion	A

Metal fragment which forms a 90 degree corner. Possibly a vessel fragment.

AE 280

Macroscopic characterisation

Description	ring
pXRF no.	VO210
metal	leaded bronze
Weight (gr)	0.57 gr
D	0.95 cm
Th. (min)	0.15 cm
Th. (max)	0.25 cm
Corrosion	B

Small ring with thick round cross-section and closed ends. The joint of the two ends can be discerned from the surface treatment of the ring (Type IVa)

AE 290

Macroscopic characterisation

Description	pendant
pXRF no.	VO082
metal	bronze
Weight (gr)	3.45 gr
L (max)	2.7 cm
H (max)	1.55 cm
Width	1.40 cm
Th. (min)	0.10 cm
Corrosion	B

Bell-shaped pendant (hollow) formed from metal sheet with suspension hole at the top part.

AE 294

Macroscopic characterisation

Description	decorative ornament/ fibula attachment
pXRF no.	VO183
metal	leaded bronze
Weight (gr)	10.04 gr
H (max)	3.10 cm
Th. (min)	0.35 cm
Th. (max)	0.90 cm
Corrosion	A

Decorative ornament with thick round cross-section body, narrower neck and plano-convex head. Possibly element from over-sized fibula catch-plate decoration.

See also AE 418, AE 577.

AE 295

Macroscopic characterisation

Description	pin
pXRF no.	VO181
metal	leaded bronze
Weight (gr)	3.14 gr
L (max)	5.85 cm
Th. (min)	0.30 cm
Th. (max)	0.35 cm
Corrosion	A

Pin fragment. The head is not preserved. The pin's rod forms a pointy, round cross-section end, while further up the rod has been twisted for decorative purposes.

AE 310

Macroscopic characterisation

Description	bird pendant (disk fragment)
pXRF no.	VO081
metal	bronze
Weight (gr)	6.54 gr
D	3.30 cm
Th. (min)	0.10 cm
Th. (max)	0.15 cm
Corrosion	A

Metal disk, fragment of bird pendant.

Typology:

Kilian (1975): plate 83, no. 5

Kalapodi (2007): plate 20, no. 160

AE 311

Macroscopic characterisation

Description	sheet
pXRF no.	VO214
metal	bronze
Weight (gr)	8.87 gr
L (max)	2.00 cm
Width	1.90 cm
Th. (min)	0.30 cm
Th. (max)	0.60 cm
Corrosion	C

Fragmented metal sheet. The sheet is flat and could not have been part of a vessel's body.

AE 386

Macroscopic characterisation

Description	biconical pendant
pXRF no.	VO163
metal	bronze
Weight (gr)	23.22 gr
L	2.80 cm
D (hole)	0.60 cm
D (ext)	2.00 cm
Th.	0.80 cm
Corrosion	C

Biconical pendant with round suspension hole.

Similar finds have been found in the tombs in northern Greece and have been grouped as Macedonian Bronzes (e.g. Vokotopoulou, 1986, 1990).

AE 417

Macroscopic characterisation

Description	vessel handle
pXRF no.	VO152
metal	bronze
Weight (gr)	12.23 gr
L (max)	4.80 cm
Width	1.25 cm
Th. (min)	0.10 cm
Th. (max)	0.40 cm
Corrosion	A

Vessel handle which would have been attached to the vessel possibly with the use of soldering, since no holes through which nails would have been used were found.

AE 418

Macroscopic characterisation

Description	decorative ornament/ fibula attachment
pXRF no.	VO184
metal	bronze
Weight (gr)	11.33 gr
H (max)	3.85 cm
Th. (min)	0.40 cm
Th. (max)	1.00 cm
Corrosion	A

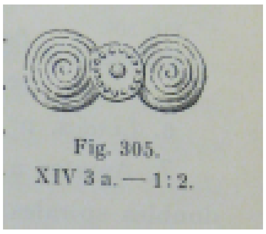
Decorative ornament with thick round cross-section body, narrower neck and plano-convex head. Possibly element from over-sized fibula catch-plate decoration.

See also AE 294, AE 577.

AE 427

Macroscopic characterisation

Description	wheel disk/ fibula attachment ?	Wheel disk with suspension hole and embossed dot-decoration. Also, possibly decoration element from spectacle fibula as seen in Blinkenberg (1926, p.259, fig. 305).
pXRF no.	VO200	
metal	zinc-rich bronze	
Weight (gr)	2.37 gr	
D	2.50 cm	
Th. (min)	0.05 cm	
Th. (max)	0.02 cm	
Corrosion	A	



AE 432

Macroscopic characterisation

Description	ring	
pXRF no.	VO193	Ring with plano-convex cross-section and close ends (Type IIb). The joint of ring's ends is visible due to its surface treatment.
metal	leaded bronze	
Weight (gr)	3.71 gr	
D	2.20 cm	
Th. (min)	0.20 cm	
Th. (max)	0.50 cm	
Corrosion	A	

AE 441

Macroscopic characterisation

Description	sheet/ vessel base?	Metal sheet, possibly part of vessel's base (or rim).
pXRF no.	VO068	
metal	leaded bronze	
Weight (gr)	13.54 gr	
L (max)	4.80 cm	
Width	3.00 cm	
Th.	0.15 cm	
Corrosion	A	


AE 451

Macroscopic characterisation

Description	bead
pXRF no.	VO219
metal	leaded bronze
Weight (gr)	0.35 gr
D	0.55 cm
Th. (min)	0.10 cm
Th. (max)	0.20 cm
Corrosion	D

Minute bead with triangular cross section and folded ends. This bead consists the only lead-rich and tin-rich bronze.

Typology:
Kalapodi (2007): plate 45, no. 1384, 1414

AE 465

Macroscopic characterisation

Description	fibula
pXRF no.	VO196
metal	bronze
Weight (gr)	8.62 gr
L (max)	6.40 cm
Th. (min)	0.55 cm
Th. (max)	1.05 cm
Corrosion	A

Epirotic fibula from which the cast bow and catch-plate have been preserved. The fibula arm and foot are missing.

Typology:
Kilian (1975): type J IIb
Blinkenberg (1926): V

AE 473

Macroscopic characterisation

Description	decorative ornament
pXRF no.	VO189
metal	bronze
Weight (gr)	2.91 gr
L (max)	1.95 cm
Width	1.60 cm
Th.	0.30 cm
Corrosion	A

Decorative element with spiral. Possibly from fibula catch-plate.

AE 483

Macroscopic characterisation

Description	ring	
pXRF no.	VO130	Ring with thick, round cross-section which is even across ring's length (Type IVa).
metal	zinc-rich bronze	
Weight (gr)	4.43 gr	
D	2.60 cm	
Th.	0.30 cm	
Corrosion	A	

AE 484

Macroscopic characterisation

Description	undiagnosed/from pendant	
pXRF no.	VO070	Part from pendant with small, round suspension hole. Typology: Kilian (1975): plate 80, no. 3, 4
metal	bronze	
Weight (gr)	9.38 gr	
L (max)	2.90 cm	
Width	0.85 gr	
Th. (min)	0.18 cm	
Th. (max)	0.75 cm	
Corrosion	A	

AE 487

Macroscopic characterisation

Description	object fragment	
pXRF no.	VO192	T-shaped fragment from object. Possibly, fragment from top part of pin (?) based on similar finds from Olympia or other metal fixtures based on find from Isthmia See also AE 116.
metal	unalloyed copper	
Weight (gr)	1.86 gr	
L (max)	3.30 cm	
Width	1.35 cm	
Th. (min)	0.15 cm	
Th. (max)	0.70 cm	
Corrosion	B	

AE 502

Macroscopic characterisation

Description	ring with attached sheet
pXRF no.	VO203A
metal	leaded bronze
Weight (gr)	3.57 gr
L (max)	2.50 cm
ring:	
D	1.90 cm
Th. (min)	0.30 cm
Th. (max)	0.40 cm
Corrosion	A

AE 502.1 relates to analyses on ring, AE 502.2 relates to analyses on the metal sheet

Ring: Type IVa

AE 508

Macroscopic characterisation

Description	ring
pXRF no.	VO206
metal	leaded bronze
Weight (gr)	15.65 gr
D (max)	3.50 cm
D (MIN)	3.05 cm
Th. (min)	0.30 CM
Th. (max)	0.50 CM
Corrosion	B

Ring with round/ovoid, thick cross-section (Type IVa). The ring's opposite sides are thinner.

AE 516

Macroscopic characterisation

Description	spiral ring
pXRF no.	VO179
metal	bronze
Weight (gr)	10.63 gr
L (max)	3.35 cm
D	2.30 cm
Th. (min)	0.20 cm
Th. (max)	0.50 cm
Corrosion	B

Spiral ring with four spirals preserved and with plano-convex cross-section (Type Va).

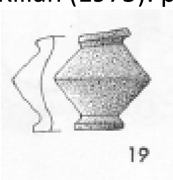
AE 533

Macroscopic characterisation

Description	biconical pendant
pXRF no.	VO185
metal	bronze
Weight (gr)	6.15 gr
L (max)	1.05 cm
D (max)	1.70 cm
D (min)	1.25 cm
D (hole)	0.80 cm
Corrosion	A

Biconical pendant/bead with wide suspension hole which falls into the category of Macedonian Bronzes. Vokotopoulou (1990) dates a similar find in the late Archaic/early Classical Periods in the early 5th century BC after a similar type from Olynthos (Type IIA).

Typology:
Vokotopoulou (1990): page 63, Tomb VI, no. 7631, page 65, Tomb IX, no. 8100
Kilian (1975): plate 76, no. 19



AE 537

Macroscopic characterisation

Description	pin/nail?
pXRF no.	VO141
metal	bronze
Weight (gr)	27.83 gr
L (max)	23.65 cm
Th. (min)	0.25 cm
Th. (max)	0.55 cm
Corrosion	C

Part of long pin (or nail) with square cross-section. The head is not preserved and it is, thus, difficult to assign it to a particular artefact type.

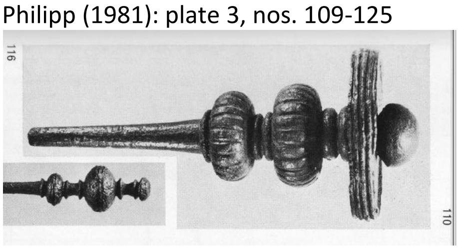
AE 538

Macroscopic characterisation

Description	pin
pXRF no.	VO042
metal	leaded bronze
Weight (gr)	61.44
L (left)	2.95 cm
D (left)	3.2 cm
L (right)	2.90 cm
D (right)	1.70 cm
Corrosion	A

Two parts from pin heads with decorative disks and floral globules. Similar finds have been found in other sites, such as in Olympia.

Typology:
Philipp (1981): plate 3, nos. 109-125



Kilian (1975): plate 65, no. 2
Kalapodi (2007): plate 28, nos. 426-427

AE 540

Macroscopic characterisation

Description	ring
pXRF no.	VO197
metal	bronze
Weight (gr)	3.75 gr
D	2.40 cm
Th. (min)	0.30 cm
Th. (max)	0.35 cm
Corrosion	B

Ring with thick, round-cross section and close ends (Type IVa). At a point, the cross-section of the ring is thinner.

AE 577

Macroscopic characterisation

Description	decorative ornament/ fibula attachment
pXRF no.	VO202
metal	bronze
Weight (gr)	11.74
H (max)	3.35 cm
Th. (min)	0.40 cm
Th. (max)	1.00 cm
Corrosion	A

Decorative ornament with thick round cross-section body, narrower neck and plano-convex head. Possibly element from over-sized fibula catch-plate decoration.

See also AE 418, AE 418.

AE 585

Macroscopic characterisation

Description	fibula
pXRF no.	VO182
metal	unalloyed copper
Weight (gr)	30.27 gr
L (max)	5.00 cm
H (max)	3.50 cm
Width	1.20 cm
Th. (min)	0.50 cm
Th. (max)	1.80 cm
Corrosion	A

Thessalian bow fibula with cast bow and decoration of a round projection at the top and two pairs of disks at the bow’s ends. The part of the bow where the catch-plate started to form is visible, but the catch-pate itself has not been preserved as with the fibula’s arm and foot.

Typology:
Kilian (1975): type D Ib
Blinkenberg (1926): Type VI

AE 614

Macroscopic characterisation

Description	object fragment
pXRF no.	VO215
metal	bronze
Weight (gr)	4.84 gr
L (max)	2.25 cm
Th. (min)	0.40 cm
Th. (max)	1.35 cm
Corrosion	A

Object fragment. Due to its poor state of preservation and fragmentation it is difficult to assign it to a particular artefact type.

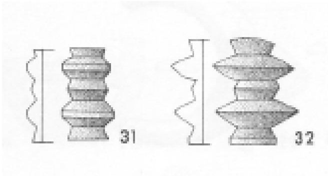
AE 615

Macroscopic characterisation

Description	biconical pendant
pXRF no.	VO204
metal	bronze
Weight (gr)	3.26 gr
L (max)	1.30 cm
D (max)	1.20 cm
D (min)	0.50 cm
D (hole)	0.45 cm
Corrosion	A

Biconical pendant/bead with suspension hole.

Typology:
Kilian (1975): plate 77, no. 31-32



AE 626

Macroscopic characterisation

Description	fibula
pXRF no.	VO178
metal	bronze
Weight (gr)	6.67 gr
L (max)	5.00 cm
Th. (min)	0.30 cm
Th. (max)	0.50 cm
Corrosion	C

Thessalian fibula bow with round cross section. The fibula's arm, catch-plate and foot have not been preserved.

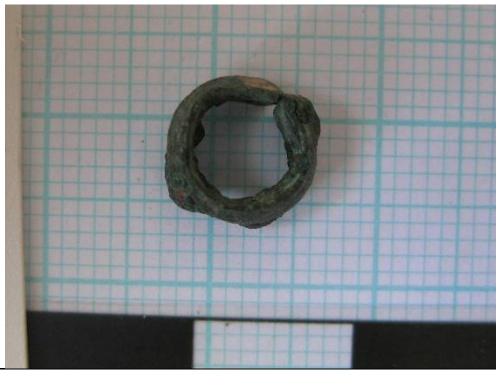
Typology:
Kilian (1975): Type B IIIa
Blinkenberg (1926): Type VI

AE 631

Macroscopic characterisation

Description	ring/bead?
pXRF no.	VO153
metal	bronze
Weight (gr)	0.73 gr
D	0.90 cm
Width	0.50 cm
Th. (max)	0.15 cm
Corrosion	C

Ring/bead with small diameter, open ends and plano-convex cross-section (Type IIb).



AE 650

Macroscopic characterisation

Description	fibula
pXRF no.	VO190
metal	bronze
Weight (gr)	12.71 gr
L (max)	7.80 cm
Th. (min)	0.40 cm
Th. (max)	0.60 cm
Corrosion	A

Fibula foot of round cross-section with part of the spring attached to the arm preserved.

AE 661

Macroscopic characterisation

Description	fibula
pXRF no.	VO151
metal	bronze
Weight (gr)	3.13 gr
L (max)	11.20 cm
Th. (min)	0.10 cm
Th. (max)	0.20 cm
Corrosion	A

Fibula foot of round cross-section with part of the spring attached to the arm preserved.

AE 680

Macroscopic characterisation

Description	ring
pXRF no.	VO208
metal	leaded bronze
Weight (gr)	2.46 gr
D	2.40 cm
Th. (min)	0.20 cm
Th. (max)	0.30 cm
Corrosion	B

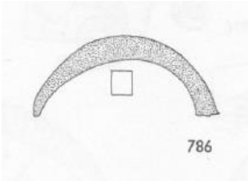
Ring with plano-convex cross section and closed ends (Type IIb).

AE 720

Macroscopic characterisation

Description	fibula
pXRF no.	VO177
metal	bronze
Weight (gr)	19.49 gr
L (max)	5.10 cm
H (max)	2.60 cm
Th. (min)	0.45 cm
Th. (max)	0.65 cm
Corrosion	B

Thessalian bow fibula with square cross-section.



Typology:
Kilian (1975): Type , plate 29, no. 786
Blinkenberg (1926): Type VI

AE 721

Macroscopic characterisation

Description	ring
pXRF no.	VO207
metal	zinc-rich leaded bronze
Weight (gr)	7.67 gr
D	3.6 cm
Th. (min)	0.35 cm
Th. (max)	0.40 cm
Corrosion	B

Ring with thick, round cross-section and closed ends (Type IVa).

AE 730

Macroscopic characterisation

Description	ring
pXRF no.	VO188
metal	leaded bronze
Weight (gr)	3.49 gr
D	2.20 cm
Th. (min)	0.20 cm
Th. (max)	0.50 cm
Corrosion	B

Ring with triangular cross-section and closed ends (Type IIa).

AE 738

Macroscopic characterisation

Description	fibula
pXRF no.	VO195
metal	bronze
Weight (gr)	15.86 gr
L (max)	3.95 cm
Th. (min)	0.65 cm
Th. (max)	1.10 cm
Corrosion	A

Thessalian bow fibula (only bow preserved with decoration of alternate globules and disks on the round cross-secction bow.

Typology:
Kilian (1975): Type B IIIp
Blinkenberg (1926): Type VI

AE 740

Macroscopic characterisation

Description	fibula
pXRF no.	VO217
metal	bronze
Weight (gr)	1.66 gr
L (max)	6.60 cm
Th. (min)	0.20 cm
Th. (max)	0.25 cm
Corrosion	C

Fibula foot of round cross-section with part of the spring attached to the arm preserved. The metallic rod has been broken in the middle.

AE 765

Macroscopic characterisation

Description	ring
pXRF no.	VO211
metal	leaded bronze
Weight (gr)	2.00 gr
D	2.30 cm
Th. (min)	0.20 cm
Th. (max)	0.30 cm
Corrosion	A

Simple wire ring with round cross-section and closed ends (Type Ia). The point where ends are joining is visible.

AE 773

Macroscopic characterisation

Description	ring
pXRF no.	VO199
metal	leaded bronze
Weight (gr)	12.68 gr
D	3.50 cm
Th. (ring)	0.45 cm
L (projection)	0.35 cm
Th. (projection)	0.15 cm
Corrosion	A

Ring with thick, round cross-section and four decorative projections (Type IVb).

AE 776.1

Macroscopic characterisation

Description	ring
pXRF no.	VO212
metal	unalloyed copper
Weight (gr)	6.66 gr
D	2.55 cm
Th. (min)	0.35 cm
Th. (max)	0.50 cm
Corrosion	B

Ring with thick round cross-section and closed ends (Type IVa).

AE 776.2

Macroscopic characterisation

Description	ring
pXRF no.	VO213
metal	bronze
Weight (gr)	0.79 gr
D	2.00 cm
Th. (min)	0.10 cm
Th. (max)	0.35 cm
Corrosion	B

Thin metal sheet ring (Type III) with no embossed or incised decoration.

AE 798

Macroscopic characterisation

Description	ring
pXRF no.	VO191
metal	leaded bronze
Weight (gr)	2.10 gr
D	2.40 cm
Th. (min)	0.20 cm
Th. (max)	0.30 cm
Corrosion	A

Simple wire ring with round cross-section and closed ends (Type Ia).

AE 806

Macroscopic characterisation

Description	ring
pXRF no.	VO201
metal	bronze
Weight (gr)	0.98 gr
D	1.60 cm
Th. (min)	0.05 cm
Th. (max)	0.01 cm
Corrosion	B

Thin metal sheet ring with embossed dot decoration (Type III).

AE 811

Macroscopic characterisation

Description	fibula
pXRF no.	VO162
metal	bronze
Weight (gr)	12.77 gr
L (max)	3.90 cm
H (max)	2.50 cm
Width	1.90 cm
Th. (min)	0.35 cm
Th. (max)	0.85 cm
Corrosion	A

Bow of Epirotic fibula with incised decoration and two decorative projections on each of its sides.

Typology:
Kilian (1975): Type K Ib or IIb
Blinkenberg (1926): Type V

AE 843

Macroscopic characterisation

Description	fibula
pXRF no.	VO180
metal	bronze
Weight (gr)	8.66 gr
L (max)	6.60 cm
H (max)	2.90 cm
Th. (min)	0.40 cm
Th. (max)	0.55 cm
Corrosion	A

Thessalian bow fibula with round cross-section and part of the coil at the joining part with the foot/arm preserved.

Typology:
Kilian (1975): Type B IIIa
Blinkenberg (1926): Type VI

AE 871

Macroscopic characterisation

Description	fibula
pXRF no.	VO218
metal	unalloyed copper
Weight (gr)	7.71 gr
L (max)	12.00 cm
Th. (max)	0.30 cm
Corrosion	A

Fibula foot of round cross-section with part of the spring attached to the arm preserved.

AE 900

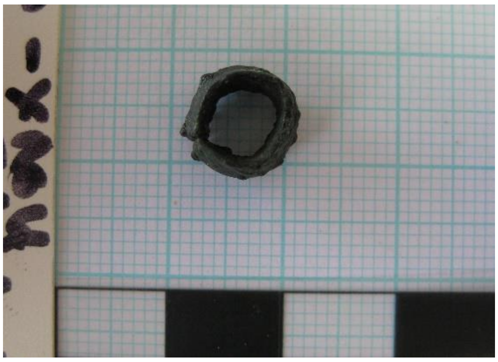
Macroscopic characterisation

Description	ring	Metal sheet ring with folded ends and no embossed or incised decoration (Type III).
pXRF no.	VO071	
metal	unalloyed copper	
Weight (gr)	1.06 gr	
D	1.30 cm	
Width	0.70 cm	
Th.	0.09 cm	
Corrosion	B	

AE 923

Macroscopic characterisation

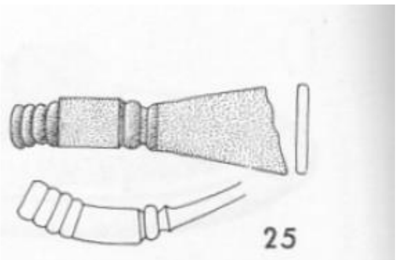
Description	ring/bead?	
pXRF no.	VO001	
metal	bronze	Ring/bead with small diameter and plano-convex cross-section (Type IIb).
Weight (gr)	1.25 gr	
D	1.00 cm	
H (max)	0.60 cm	
Th. (min)	0.10 cm	
Th. (max)	0.40 cm	
Corrosion	A	



AE 928

Macroscopic characterisation

Description	arm band	Part from arm band/armlet with decoration elements, including incised decoration. Typology: Kilian (1975): plate 68, no. 25, plate 69, no. 4
pXRF no.	VO126	
metal	bronze	
Weight (gr)	17.24 gr	
L (max)	4.30 cm	
Width	1.20 cm	
Th. (min)	0.30 cm	
Th. (max)	0.80 cm	
Corrosion	C	



AE 936			
Macroscopic characterisation			
Description	ring/sheet?	Metal sheet ring with open ends (Type III). This ring is distinguished by the rest of the rings in the Type III group, but it has been classified as such since it is formed of a metal sheet, despite that the sheet's width, thickness and decoration are different.	
pXRF no.	VO142		
metal	unalloyed copper		
Weight (gr)	2.40 gr		
D	approx. 2.50 cm		
H (max)	0.50 cm		
Th. (min)	0.10 cm		
Th. (max)	0.15 cm		
Corrosion	A		
M 214.2			
Macroscopic characterisation			
Description	fibula	Helladic fibula with globule decoration on its bow and large, square catch-plate with incised decoration. Typology: Kilian (1975): Type E I Blinkenberg (1926): Type VII	
pXRF no.	VO034		
metal	bronze		
Weight (gr)	12.42 gr		
L (max)	3.15 cm		
H (max)	2.00 cm		
Th.	0.10 cm		
Corrosion	B		
M 226.1			
Macroscopic characterisation			
Description	fibula	Oversized Thessalian bow fibula with alternate decorative globules and disks on its bow. The globules are hollow as the result of the lost-wax technique which has been used during their casting. Typology: Kilian (1975): Type D IIIq Blinkenberg (1926): Type VI	
pXRF no.	VO100		
metal	leaded bronze		
Weight (gr)	112.55 gr		
L (max)	7.60 cm		
H (max)	2.60 cm		
Width	1.30 cm		
Th. (min)	0.20 cm		
Th. (max)	0.40 cm		
Corrosion	B		

M 226.2

Macroscopic characterisation

Description	fibula	Oversized Thessalian bow fibula with alternate decorative globules and disks on its bow. The globules are hollow as the result of the lost-wax technique which has been used during their casting. Typology: Kilian (1975): Type D IIIq Blinkenberg (1926): Type VI
pXRF no.	VO099	
metal	bronze	
Weight (gr)	99.79 gr	
L (max)	8.10 cm	
H (max)	5.00 cm	
Th. (min)	0.90 cm	
Th. (max)	2.65 cm	
Corrosion	B	

M 262

Macroscopic characterisation

Description	fibula	Helladic fibula with globule and disks decoration on its bow and incised decoration on its large, square catch-plate. The globule is hollow as the result of the lost-was technique. Typology: Kilian (1975): Type F IIIc Blinkenberg (1926): Type VII
pXRF no.	VO035	
metal	bronze	
Weight (gr)	112.60 gr	
L (max)	10.50 cm	
H (max)	9.50 cm	
Th. (min)	0.01 cm	
Th. (max)	2.60 cm	
Corrosion	B	

M 282

Macroscopic characterisation

Description	fibula	Catch-plate from oversized bow fibula. The catch plate could belong to wither the Thessalian or the Epirotic type. Taking into consideration that in the assemblage all the oversized bows were of the Thessalian type, the catch-plate is also more likely to be of this type. Typology: Kilian (1975): Type A-K Blinkenberg (1926): Type VI
pXRF no.	VO032	
metal	leaded bronze	
Weight (gr)	33.53 gr	
L (max)	10.50 cm	
H (max)	6.00 cm	
Width	0.60 cm	
Th. (min)	0.10 cm	
Th. (max)	0.70 cm	
Corrosion	C	

M 338

Macroscopic characterisation

Description	fibula		
pXRF no.	VO009	Helladic fibula (bow, catch-plate and arm) with decoration of three globules on the bow. Typology: Kilian (1975): Type VIc Blinkenberg (1926): Type VII	
metal	bronze		
Weight (gr)	41.39 cm		
L (max)	7.50 cm		
H (max)	6.00 cm		
Th. (min)	0.15 cm		
Th. (max)	0.70 cm		
Corrosion	B		

M 339

Macroscopic characterisation

Description	fibula		
pXRF no.	VO031	Epirotic fibula bow with incised decoration Typology: Kilian (1975): Type J IIb Blinkenberg (1926): Type V	
metal	bronze		
Weight (gr)	18.63 gr		
L (max)	3.70 cm		
H (max)	2.20 cm		
Th. (min)	1.10 cm		
Th. (max)	1.90 cm		
Corrosion	C		

M 363

Macroscopic characterisation

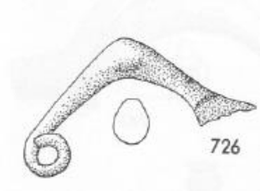
Description	fibula		
pXRF no.	VO011	Thessalian fibula bow with decorative projection at the top and two pairs of disks on each side. Typology: Kilian (1975): Type D Ib Blinkenberg (1926): Type VI	
metal	bronze		
Weight (gr)	20.46 gr		
L (max)	4.40 cm		
H (max)	3.40 cm		
Th. (min)	0.40 cm		
Th. (max)	1.20 cm		
Corrosion	B		

M 538

Macroscopic characterisation

Description	fibula
pXRF no.	VO088
metal	bronze
Weight (gr)	11.10 gr
L (max)	5.20 cm
H (max)	2.60 cm
Width	0.70 cm
Th. (min)	0.30 cm
Th. (max)	0.90 cm
Corrosion	C

Thessalian fibula bow of triangular shape and ovoid cross-section.



Typology:
Kilian (1975): Type C VII
Blinkenberg (1926): Type VI

M 680.1

Macroscopic characterisation

Description	decorative pendant
pXRF no.	VO160
metal	bronze
Weight (gr)	1.60 gr
L (max)	2.25 cm
H (max)	2.00 cm
D (single spiral)	1.05 cm
Th.	0.15 cm
Corrosion	A

Decorative ornament/pendant with double spiral decoration.

Typology:
Kilian (1975): plate 78, nos. 66-67

M 745.1

Macroscopic characterisation

Description	fibula
pXRF no.	VO120
metal	bronze
Weight (gr)	6.13 gr
L (max)	5.80 cm
H (max)	2.50 cm
Width	0.70 cm
Th. (min)	0.15 cm
Th. (max)	0.50 cm
Corrosion	A

Epirotic bow fibula. Only the catch-plate’s end is fragmented while other otherwise the fibula has a good preservation state.

Typology:
Kilian (1975): Type K IIa
Blinkenberg (1926): Type V

M 745.2

Macroscopic characterisation

Description	fibula
pXRF no.	VO124
metal	leaded bronze
Weight (gr)	4.23 gr
L (max)	6.65 cm
H (max)	0.65 cm
Width	2.15 cm
Th. (min)	0.15 cm
Th. (max)	0.35 cm
Corrosion	A

Epirotic fibula with bow and long catch-plate.

Typology:
Kilian (1975): Type K Ia
Blinkenberg (1926): Type V

M 745.3

Macroscopic characterisation

Description	fibula
pXRF no.	VO121
metal	leaded bronze
Weight (gr)	10.68 gr
L (max)	7.20 cm
H (max)	2.90 cm
Width	0.80 cm
Th. (min)	0.20 cm
Th. (max)	0.50 cm
Corrosion	A

Epirotic fibula with bow and long catch-plate and incised decoration on the bow.

Typology:
Kilian (1975): Type K Ia
Blinkenberg (1926): Type V

M 745.4

Macroscopic characterisation

Description	fibula
pXRF no.	VO123
metal	leaded bronze
Weight (gr)	4.10 gr
L (max)	2.70 cm
H (max)	1.90 cm
Width	0.70 cm
Th. (min)	0.30 cm
Th. (max)	0.50 cm
Corrosion	A

Epirotic fibula bow and incised decoration.

Typology:
Kilian (1975): Type K Ia
Blinkenberg (1926): Type V

M 745.5

Macroscopic characterisation

Description	fibula
pXRF no.	VO122
metal	leaded bronze
Weight (gr)	2.08 gr
L (max)	4.50 cm
H (max)	0.50 cm
Width	0.25 cm
Th. (min)	0.08 cm
Th. (max)	0.15 cm
Corrosion	A

Long catch-plate and foot with part of arm-spring preserved from Epirotic fibula.

Typology:
Kilian (1975): Type K Ia
Blinkenberg (1926): Type V

M 757

Macroscopic characterisation

Description	fibula
pXRF no.	VO067
metal	bronze
Weight (gr)	42.54 gr
L (max)	6.00 cm
H (max)	5.40 cm
Width	1.30 cm
Th. (min)	0.10 cm
Th. (max)	1.50 cm
Corrosion	A

Thessalian bow fibula with globule/disk decoration on the bow and elongated catch-plate with upright projection with small globule decoration. The arm and foot have not been preserved.

Typology:
Kilian (1975): Type C III
Blinkenberg (1926): Type VI

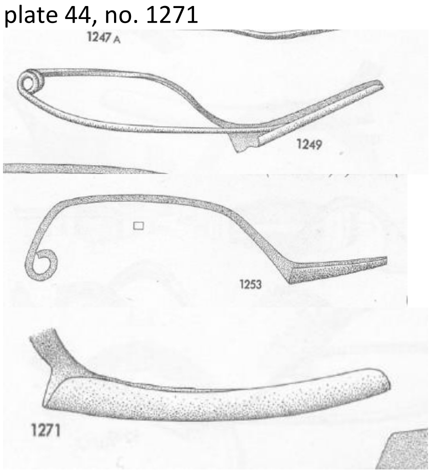
M 775

Macroscopic characterisation

Description	fibula
pXRF no.	VO033
metal	bronze
Weight (gr)	8.18 gr
L (max)	7.40 cm
Width	0.60 cm
Th. (min)	0.15 cm
Th. (max)	0.35 cm
Corrosion	A

Bow fibula with wire bow and long catch-plate. The bow possible was decorated with perishable materials, e.g. wood.

Typology:
Kilian (1975): plate 43, nos. 1249, 1253, plate 44, no. 1271



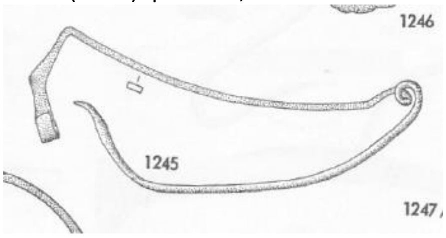
M 776.1

Macroscopic characterisation

Description	fibula
pXRF no.	VO027
metal	unalloyed copper
Weight (gr)	8.51 gr
L (max)	8.00 cm
Th. (min)	0.15 cm
Th. (max)	0.35 cm
Corrosion	B

Fibula with wire bow.

Typology:
Kilian (1975): plate 43, no. 1245



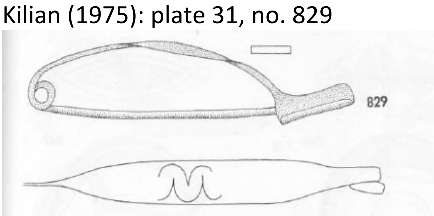
M 776.2

Macroscopic characterisation

Description	fibula
pXRF no.	VO028
metal	unalloyed copper
Weight (gr)	4.19 gr
L (max)	7.30 cm
H (max)	2.70 cm
Th. (min)	0.10 cm
Th. (max)	0.40 cm
Corrosion	A

Fibula with sheet bow. Two projections on the bow suggest that additional decoration would have been in place.

Typology:
Kilian (1975): plate 31, no. 829



M 776.3

Macroscopic characterisation

Description	fibula
pXRF no.	VO029
metal	unalloyed copper
Weight (gr)	1.25 gr
L (max)	3.20 cm
H (max)	1.30 cm
Th. (min)	0.10 cm
Th. (max)	0.25 cm
Corrosion	A

Miniature Thessalian bow fibula with round cross-section. The arm spring has been unfolded open. The catch-plate is not preserved.

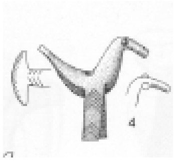
Typology:
Kilian (1975): Type A IIIa.b
Blinkenberg (1926): Type VI

M 786

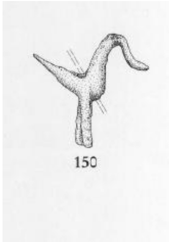
Macroscopic characterisation

Description	bird pendant	Bird pendant with elongated, thin beak, tail and legs.
pXRF no.	VO056	
metal	bronze	
L (max)	2.20 cm	
H (max)	1.80 cm	
Corrosion	C	

Typology:
Kilian (1975): plate 85, no. 4



Kalapodi (2007): plate 20, nos. 150, 155

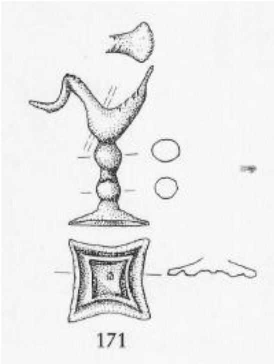


M 884

Macroscopic characterisation

Description	bird pendant	Bird pendant with square, seal base.
pXRF no.	VO008	
metal	bronze	
Weight (gr)	31.58 gr	
L (max)	3.40 cm	
H (max)	5.50 cm	
Th. (min)	0.30 cm	
Th. (max)	1.10 cm	
Corrosion	B	

Typology:
Kilian (1975): plate , no. 171



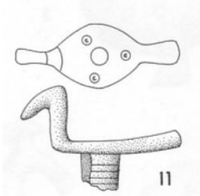
M 885

Macroscopic characterisation

Description	bird pendant fibula	Bird pendant with flat back with suspension hole, and elongated beak/tail.
pXRF no.	VO057	
metal	leaded bronze	
Weight (gr)	7.51 gr	
L (max)	3.90 cm	
H (max)	2.10 cm	
Width	1.50 cm	
Th.	0.30 cm	
Corrosion	A	

Typology:
Kilian (1975):
plate 81, no. 33

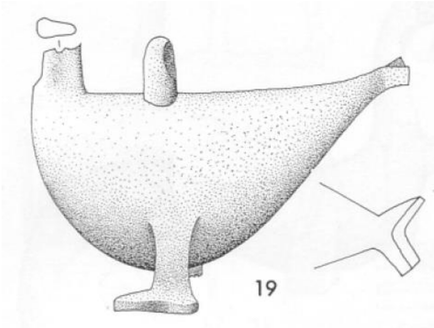
plate 85, no.11



M 926.1

Macroscopic characterisation

Description	bird pendant fibula	Hen pendant, dated to around 700 BC (Voyatzis, 1990). Typology: Kilian (1975): plate 85, no. 19
pXRF no.	VO127	
metal	leaded bronze	
Weight (gr)	72.46 gr	
L (max)	5.90 cm	
H (max)	4.50 cm	
Width	2.80 cm	
Corrosion	C	



M 926.2

Macroscopic characterisation

Description	bird pendant	Hen pendant, dated to around 700 BC (Voyatzis, 1990). Typology: Kilian (1975): plate 85, no. 19. See also M 2293
pXRF no.	VO128	
metal	bronze	
Weight (gr)	80.62 gr	
L (max)	5.90 cm	
H (max)	4.00 cm	
Width	3.60 cm	
Corrosion	C	

M 1225

Macroscopic characterisation

Description	fibula	Attic-boeotian (Helladic) fibula with large square catch-plate and incised decoration. Typology: Kilian (1975): Type B Ib; Blinkenberg (1926): Type VIII
pXRF no.	VO077	
metal	bronze	
Weight (gr)	42.05 gr	
L (max)	13.50 cm	
H (max)	7.00 cm	
Th. (min)	0.10 cm	
Th. (max)	0.75 cm	
Corrosion	B	

M 1315.1

Macroscopic characterisation

Description	fibula
pXRF no.	VO004
metal	bronze
Weight (gr)	15.84 gr
L (max)	4.10 cm
Width	1.80 cm
Th. (min)	0.10 cm
Th. (max)	0.40 cm
Corrosion	B

Attic-boeotian fibula. The catch-plate and foot have not been preserved.

Typology:
Kilian (1975): Type A IIa
Blinkenberg (1926): Type VIII

M 1315.2

Macroscopic characterisation

Description	fibula
pXRF no.	VO005
metal	bronze
Weight (gr)	17.90 gr
L (max)	4.20 cm
H (max)	0.70 cm
Width	2.50 cm
Th. (min)	0.35 cm
Corrosion	B

Epirotic bow fibula with square cross-section and a pair of side projections with incised cross decoration.

Typology:
Kilian (1975): Type K Id
Blinkenberg (1926): Type V

M 1345.1

Macroscopic characterisation

Description	fibula
pXRF no.	VO111
metal	bronze
Weight (gr)	2.75 gr
L (max)	5.10 cm
H (max)	2.20 cm
Width	0.30 cm
Th. (min)	0.20 cm
Th. (max)	0.30 cm
Corrosion	C

Miniature Thessalian bow fibula from simple, round-cross section wire.

Typology:
Kilian (1975): Type A IIa

M 1345.2

Macroscopic characterisation

Description	fibula
pXRF no.	VO112
metal	bronze
Weight (gr)	2.83 gr
L (max)	5.60 cm
H (max)	2.20 cm
Width	0.20 cm
Th. (min)	0.12 cm
Th. (max)	0.20 cm
Corrosion	C

Thessalian bow fibula from simple, round-cross section wire.

Typology:
Kilian (1975): Type A IIb

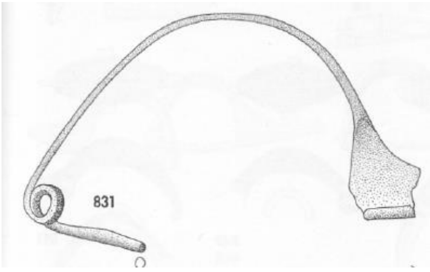
M 1345.3

Macroscopic characterisation

Description	fibula
pXRF no.	VO113
metal	zinc-rich unalloyed copper
Weight (gr)	2.16 gr
L (max)	5.10 cm
H (max)	2.80 cm
Width	0.20 cm
Th. (min)	0.15 cm
Th. (max)	0.20 cm
Corrosion	C

Wire bow Thessalian fibula and simple arm spring.

Typology:
Kilian (1975): plate 31, no. 831, Type F II



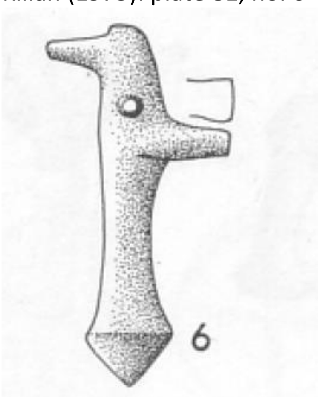
M 1358.1

Macroscopic characterisation

Description	bird pendant
pXRF no.	VO061
metal	bronze
Weight (gr)	9.38 gr
L (max)	4.40 cm
Width	2.20 cm
Th.	0.50 cm
Corrosion	B

Bird pendant with small suspension hole.

Typology:
Kilian (1975): plate 81, no. 6



M 1358.2

Macroscopic characterisation

Description	bird pendant fragment (?)
pXRF no.	VO059
metal	bronze
Weight (gr)	2.99 gr
L (max)	2.35 cm
H (max)	1.60 cm
Width	0.60 cm
Th. (min)	0.40 cm
Corrosion	C

Fragment of bird pendant.

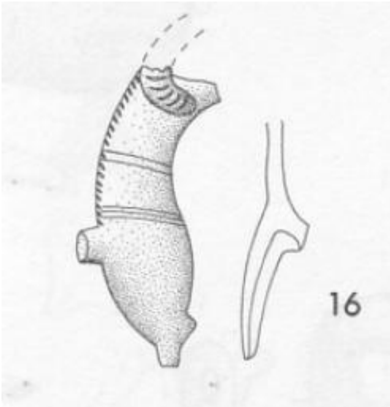
M 1358.3

Macroscopic characterisation

Description	horse figurine
pXRF no.	VO060
metal	bronze
Weight (gr)	8.25 gr
L (max)	4.30 cm
Width	1.50 cm
Th.	0.30 cm
Corrosion	B

Fragment from horse figurine.

Typology:
Kilian (1975): plate 86, no. 16



Kalapodi (2007): plate 18, no. 119

M 1413

Macroscopic characterisation

Description	fibula
pXRF no.	VO063
metal	bronze
Weight (gr)	26.67 gr
L (max)	4.00 cm
H (max)	4.20 cm
Width	1.00 cm
Th. (min)	0.10 cm
Th. (max)	1.30 cm
Corrosion	C

Phrygian fibula bow with square elements' decoration.

Typology:
Kilian (1975): Phrygian, plate 59
Blinkenberg (1926): Type XII

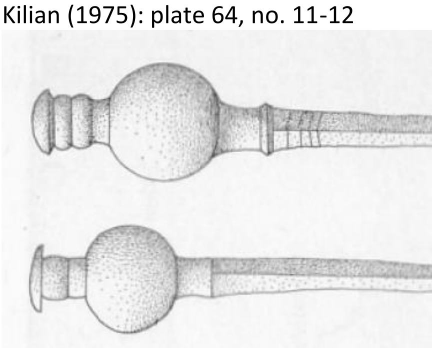
M 1433

Macroscopic characterisation

Description	pin
pXRF no.	VO044
metal	bronze
Weight (gr)	22.53 gr
L (max)	5.60 cm
D (globule)	1.50 cm
Th. (min)	0.20 cm
Th. (max)	0.60 cm
Corrosion	B

Pin with disk and round globule on the head.

Typology:
Kilian (1975): plate 64, no. 11-12



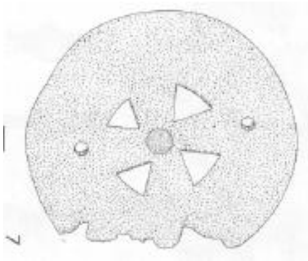
M 1512.3

Macroscopic characterisation

Description	fibula
pXRF no.	VO016
metal	bronze
Weight (gr)	22.68 gr
D	6.40 cm
Th.	0.15 cm
Corrosion	B

Wheel disk with two suspension holes and four decorative triangles and a projection at its centre.

Typology:
Kilian (1975): plate 79, no. 7



Philipp (1981): plate 76, no. 1238

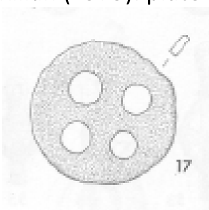
M 1512.4

Macroscopic characterisation

Description	wheel disk
pXRF no.	VO015
metal	bronze
Weight (gr)	12.37 gr
D	6.00 cm
Th.	0.15 cm
Corrosion	B

Wheel disk pendant with four round/ovoid decorative/suspension holes close to its centre.

Typology:
Kilian (1975): plate 79, nos. 17-18



Philipp (1981): plate 76, no. 1233

M 1518

Macroscopic characterisation

Description	wheel disk/ pendant
pXRF no.	VO043
metal	bronze
Weight (gr)	18.87 gr
L (max)	8.20 cm
D	7.10 cm
Th. (min)	0.20 cm
Th. (max)	0.40 cm
Corrosion	A

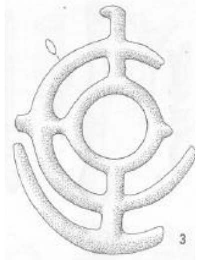
Decorative wheel disk pendant from metal wire of ovoid cross-section

Typology:
Similar finds include disks from:

Agrosykia (Chrysostomou, 2007, pl. III.25, no. 2

Isthmia (1998, pl. 9, no. 42)

Kilian (1975): plate 79, no. 3



M 1585.2

Macroscopic characterisation

Description	fibula
pXRF no.	VO026
metal	leaded bronze
Weight (gr)	35.56 gr
L (max)	4.80 cm
H (max)	4.20 cm
Width	2.40 cm
Th. (min)	0.20 cm
Th. (max)	0.80 cm
Corrosion	A

Epirotic fibula bow with a pair of side projections and part of the catch-plate preserved.

Typology:
Kilian (1975): Type K Ib
Blinkenberg (1926): Type V

M 1646

Macroscopic characterisation

Description	fibula
pXRF no.	VO085
metal	bronze
Weight (gr)	25.94 gr
L (max)	6.20 cm
H (max)	0.70 cm
D (single spiral)	2.70 cm
Th.	0.35 cm
Corrosion	C

Spectacle fibula with round cross-section and double S-shaped coil between the two large spirals.

Typology:
Kilian (1975): Type B II
Blinkenberg (1926): Type XIV

M 1661.1

Macroscopic characterisation

Description	fibula
pXRF no.	VO092
metal	leaded bronze
Weight (gr)	40.49 gr
L (max)	5.00 cm
H (max)	4.90 cm
Width	2.90 cm
Th. (min)	0.08 cm
Th. (max)	0.70 cm
Corrosion	C

Epirotic fibula bow with a pair of side projections and part of the catch-plate preserved.

Typology:
Kilian (1975): Type K Ib
Blinkenberg (1926): Type V

M 1661.2

Macroscopic characterisation

Description	fibula
pXRF no.	VO095
metal	bronze
Weight (gr)	29.91 gr
L (max)	10.40 cm
H (max)	3.20 cm
Width	2.30 cm
Th. (min)	0.15 cm
Th. (max)	1.00 cm
Corrosion	B

Epirotic fibula with round bow and arm with spring and foot preserved

Typology:
Kilian (1975): Type K Ib or IIb
Blinkenberg (1926): Type V

M 1661.3

Macroscopic characterisation

Description	fibula
pXRF no.	VO093
metal	leaded bronze
Weight (gr)	12.69 gr
L (max)	7.50 cm
H (max)	2.80 cm
Width	1.70 cm
Th. (min)	0.25 cm
Th. (max)	0.65 cm
Corrosion	B

Epirotic bow fibula with a pair of side projections on the bow. The catch-plate is not preserved.

Typology:
Kilian (1975): Type K Ib
Blinkenberg (1926): Type V

M 1661.4

Macroscopic characterisation

Description	fibula
pXRF no.	VO089
metal	bronze
Weight (gr)	14.54 gr
L (max)	4.50 cm
H (max)	3.90 cm
Width	1.85 cm
Th. (min)	0.50 cm
Th. (max)	0.70 cm
Corrosion	C

Epirotic fibula bow with a pair of side projections and incised decoration.

Typology:
Kilian (1975): Type K Ib or IIb
Blinkenberg (1926): Type V

M 1661.5

Macroscopic characterisation

Description	fibula
pXRF no.	VO094
metal	leaded bronze
Weight (gr)	13.88 gr
L (max)	8.30 cm
H (max)	4.20 cm
Width	1.70 cm
Th. (min)	0.20 cm
Th. (max)	0.70 cm
Corrosion	C

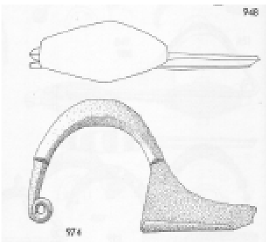
Typology:
Kilian (1975): Type
Blinkenberg (1926): Type

M 1661.6

Macroscopic characterisation

Description	fibula
pXRF no.	VO091
metal	leaded bronze
Weight (gr)	
L (max)	
H (max)	
Width	
Th. (min)	
Th. (max)	
Corrosion	

Typology:
Kilian (1975): Type
Blinkenberg (1926): Type



M 1661.7

Macroscopic characterisation

Description	fibula
pXRF no.	VO090
metal	bronze
Weight (gr)	17.85 gr
L (max)	3.90 cm
H (max)	2.00 cm
Width	2.00 cm
Th. (min)	0.50 cm
Th. (max)	0.90 cm
Corrosion	C

Typology:
Kilian (1975): Type
Blinkenberg (1926): Type

M 1666.1

Macroscopic characterisation

Description	fibula
pXRF no.	VO003
metal	leaded bronze
Weight (gr)	221.01 gr
L (max)	10.70 cm
H (max)	7.50 cm
Th. (min)	1.40 cm
Th. (max)	3.35 cm
Corrosion	C

Typology:
Kilian (1975): Type
Blinkenberg (1926): Type

M 1666.2

Macroscopic characterisation

Description	fibula
pXRF no.	VO001
metal	bronze
Weight (gr)	179.30 gr
L (max)	9.10 cm
H (max)	4.60 cm
Th. (min)	1.40 cm
Th. (max)	3.50 cm
Corrosion	B

Typology:
Kilian (1975): Type
Blinkenberg (1926): Type

M 1666.3

Macroscopic characterisation

Description	fibula
pXRF no.	VO002
metal	bronze
Weight (gr)	129.94 gr
L (max)	7.60 cm
Th. (min)	1.50 cm
Th. (max)	3.40 cm
Corrosion	B

Typology:
Kilian (1975): Type
Blinkenberg (1926): Type

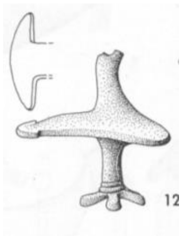
M 1683.1

Macroscopic characterisation

Description	bird pendant
pXRF no.	VO052
metal	leaded bronze
Weight (gr)	34.43 gr
L (max)	4.45 cm
H (max)	4.30 cm
Width	2.40 cm
Th. (min)	0.40 cm
Corrosion	B

Bird pendant from Laconian workshop with large, flat tail and long neck, legs (see also M 1683.2).

Typology:
Kilian (1975): plate 85, no. 12
Similar pendant also found in Lagaria, in south Italy.



M 1731.1

Macroscopic characterisation

Description	fibula	Complete Epirotic bow fibula. Typology: Kilian (1975): Type K IIa Blinkenberg (1926): Type V
pXRF no.	VO119	
metal	bronze	
Weight (gr)	5.34 gr	
L (max)	5.85 cm	
H (max)	2.40 cm	
Th. (min)	0.15 cm	
Th. (max)	0.40 cm	
Corrosion	B	

M 1731.2

Macroscopic characterisation

Description	fibula	Epirotic bow fibula with decorative projection at the top of the bow. Typology: Kilian (1975): Type K Ia or IIa Blinkenberg (1926): Type V
pXRF no.	VO075	
metal	bronze	
Weight (gr)	3.22 gr	
L (max)	5.85 cm	
H (max)	2.80 cm	
Width	0.50 cm	
Th. (min)	0.18 cm	
Th. (max)	0.35 cm	
Corrosion	B	

M 1731.3

Macroscopic characterisation

Description	fibula	Epirotic bow fibula. The foot is not preserved. Typology: Kilian (1975): Type IIa Blinkenberg (1926): Type V
pXRF no.	VO118	
metal	leaded bronze	
Weight (gr)	4.44 gr	
L (max)	6.30 cm	
H (max)	2.90 cm	
Width	0.55 cm	
Th. (min)	0.07 cm	
Th. (max)	0.35 cm	
Corrosion	B	

M 1731.4

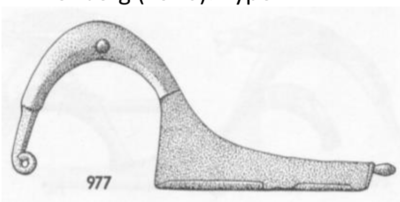
Macroscopic characterisation

Description	fibula	Epirotic fibula bow with a pair of projections on the bow's each side. Part of the arm coil and catch-plate are preserved. Typology: Kilian (1975): Type IIa Blinkenberg (1926): Type V
pXRF no.	VO117	
metal	leaded bronze	
Weight (gr)	2.34 gr	
L (max)	3.30 cm	
H (max)	2.00 cm	
Width	0.50 cm	
Th. (min)	0.20 cm	
Th. (max)	0.31 cm	
Corrosion	B	

M 1734.1

Macroscopic characterisation

Description	fibula	Epirotic bow fibula with a pair of projections on bow's each side and elongated catch-plate. Typology: Kilian (1975): Type K Ib, plate 34, no. 977 Blinkenberg (1926): Type V
pXRF no.	VO106	
metal	leaded bronze	
Corrosion	C	



M 1734.2

Macroscopic characterisation

Description	fibula	Epirotic bow fibula with a pair of projections on bow's each side and elongated catch-plate. The foot is also preserved. Typology: Kilian (1975): Type K Ib, plate 34, no. 977 Blinkenberg (1926): Type V
pXRF no.	VO108	
metal	bronze	
Corrosion	D	

M 1734.3

Macroscopic characterisation

Description	fibula	Epirotic fibula bow with a pair of projections on the bow's each side and incised decorations. Typology: Kilian (1975): Type K Ib or IIb Blinkenberg (1926): Type V
pXRF no.	VO107	
metal	leaded bronze	
Weight (gr)	33.25 gr	
L (max)	4.80 cm	
H (max)	4.20 cm	
Width	2.70 cm	
Th. (min)	0.60 cm	
Th. (max)	1.05 cm	
Corrosion	B	

M 1734.4

Macroscopic characterisation

Description	fibula	Epirotic bow fibula with a pair of side projections on the bow's each side. The fibula is severely corroded. Typology: Kilian (1975): Type Ib or IIb Blinkenberg (1926): Type V
pXRF no.	VO109	
metal	bronze	
Corrosion	C	

M 1734.5

Macroscopic characterisation

Description	fibula
pXRF no.	VO110
metal	leaded bronze
Corrosion	B

Epirotic bow fibula with a pair of side projections on the bow's each side.

Typology:
Kilian (1975): Type K Ib
Blinkenberg (1926): Type V

M 1735.1

Macroscopic characterisation

Description	fibula
pXRF no.	VO103
metal	bronze
Weight (gr)	35.88 gr
L (max)	10.05 cm
H (max)	4.50 cm
Width	2.50 cm
Th. (min)	0.10 cm
Th. (max)	0.90 cm
Corrosion	B

Epirotic bow fibula with a pair of side projections on the bow's each side and elongated catch-plate. The foot is preserved.

Typology:
Kilian (1975): Type K Ib
Blinkenberg (1926): Type V

M 1735.2

Macroscopic characterisation

Description	fibula
pXRF no.	VO104
metal	unalloyed copper
Weight (gr)	35.27 gr
L (max)	10.60 cm
H (max)	4.50 cm
Width	2.20 cm
Th. (min)	0.08 cm
Th. (max)	0.70 cm
Corrosion	C

Epirotic bow fibula with a pair of side projections on the bow's each side and elongated catch-plate.

Typology:
Kilian (1975): Type K Ib
Blinkenberg (1926): Type V

M 1735.3

Macroscopic characterisation

Description	fibula
pXRF no.	VO105
metal	bronze
Weight (gr)	10.35 gr
L (max)	3.60 cm
H (max)	2.50 cm
Width	1.35 cm
Th. (min)	0.4 cm
Th. (max)	1.15 cm
Corrosion	C

Epirotic bow fibula with a pair of side projections on the bow's each side and incised decoration.

Typology:
Kilian (1975): Type K Ib
Blinkenberg (1926): Type V

M 1735.4

Macroscopic characterisation

Description	fibula
pXRF no.	VO102
metal	bronze
Weight (gr)	35.79 gr
L (max)	5.90 cm
H (max)	4.80 cm
Width	2.25 cm
Th. (min)	0.05 cm
Th. (max)	0.09 cm
Corrosion	

Elongated catch-plate from Epirotic fibula.

Typology:
Kilian (1975): Type K Ib or IIb
Blinkenberg (1926): Type V

M 1794

Macroscopic characterisation

Description	fibula
pXRF no.	VO013
metal	bronze
Weight (gr)	13.75 gr
L (max)	8.70 cm
H (max)	3.35 cm
Th. (min)	0.20 cm
Th. (max)	1.50 cm
Corrosion	A

Complete Epirotic fibula with a pair of side projections on the bow's each side and elongated catch-plate with coil between the foot and arm.

Typology:
Kilian (1975): Type K Ib
Blinkenberg (1926): Type V

M 1801.1

Macroscopic characterisation

Description	arm band
pXRF no.	VO146
metal	bronze
Weight (gr)	78.44 gr
D	9.30 cm
Width	0.70 cm
Th. (min)	0.50 cm
Th. (max)	0.60 cm
Corrosion	C

Arm band/armlet or large open ring with square cross-section.

Typology:
Kilian (1975): plate 66, no. 24

M 1801.2

Macroscopic characterisation

Description	arm band
pXRF no.	VO145
metal	bronze
Weight (gr)	22.88 gr
D	7.30 cm
Width	0.75 cm
Th.	0.35 cm
Corrosion	D

Arm band/armlet with decorated open ends.

Typology:
Kilian (1975): plate 68, no. 4

M 1801.3

Macroscopic characterisation

Description	arm band
pXRF no.	VO144
metal	bronze
Weight (gr)	7.82 gr
D	5.80 cm
Th.	0.30 cm
Corrosion	C

Arm band/armlet with decorated open ends.

Typology:
Kilian (1975): plate 68

M 1801.4

Macroscopic characterisation

Description	arm band
pXRF no.	VO143
metal	bronze
Weight (gr)	14.38 gr
D	4.40 cm
Width	0.50 cm
Th.	0.30 cm
Corrosion	C

Arm band/armlet with open, folded/overlapping ends.

Typology:
Kilian (1975): plate 67

M 1812.1

Macroscopic characterisation

Description	fibula
pXRF no.	VO037
metal	bronze
Weight (gr)	2.78 gr
L (max)	4.60 cm
Th. (min)	0.20 cm
Th. (max)	0.30 cm
Corrosion	C

Miniature Thessalian fibula with round cross-section bow.

Typology:
Kilian (1975): Type A IIa

M 1812.2

Macroscopic characterisation

Description	fibula
pXRF no.	VO038
metal	bronze
Weight (gr)	6.29 gr
L (max)	2.70 cm
H (max)	2.00 cm
Width	0.90 cm
Th. (min)	0.30 cm
Th. (max)	0.70 cm
Corrosion	C

Epirotic fibula bow with no further decoration.

Typology:
Kilian (1975): Type K IIa
Blinkenberg (1926): Type V

M 1812.3

Macroscopic characterisation

Description	fibula
pXRF no.	VO036
metal	bronze
Weight (gr)	2.26 gr
L (max)	1.80 cm
H (max)	1.60 cm
Width	0.65 cm
Th. (min)	0.25 cm
Th. (max)	0.50 cm
Corrosion	C

Epirotic fibula bow with no further decoration.

Typology:
Kilian (1975): Type K IIa
Blinkenberg (1926): Type V

M 1815.1

Macroscopic characterisation

Description	fibula
pXRF no.	VO098
metal	bronze
Weight (gr)	4.64 gr
L (max)	6.20 cm
H (max)	2.10 cm
Width	0.40 cm
Th. (min)	0.20 cm
Th. (max)	0.35 cm
Corrosion	C

Complete Epirotic fibula with elongated catch-plate.

Typology:
Kilian (1975): Type K Ia
Blinkenberg (1926): Type V

M 1815.3

Macroscopic characterisation

Description	fibula
pXRF no.	VO097
metal	bronze
Weight (gr)	4.27 gr
L (max)	3.30 cm
H (max)	1.90 cm
Width	1.30 cm
Th. (min)	0.25 cm
Th. (max)	0.40 cm
Corrosion	B

Epirotic fibula bow with a pair of side projections and incised decoration.

Typology:
Kilian (1975): Type K Ib
Blinkenberg (1926): Type V

M 1815.4

Macroscopic characterisation

Description	fibula
pXRF no.	VO096
metal	bronze
Weight (gr)	15.71 gr
L (max)	4.40 cm
H (max)	3.70 cm
Width	1.00 cm
Th. (min)	0.40 cm
Th. (max)	1.20 cm
Corrosion	C

Thessalian bow fibula with decoration of alternate round globules and disk on the bow.

Typology:
Kilian (1975): Type C IIIk
Blinkenberg (1926): Type VI

M 1843.1

Macroscopic characterisation

Description	fibula
pXRF no.	VO050A
metal	brass
Weight (gr)	6.40 gr
L (max)	3.80 cm
H (max)	3.90 cm
Width	0.60 cm
Th.	0.15
Corrosion	A

Horse-shoe shaped fibula with a pair of holes for the foot. Note: this is the only brass object in the sample with 9% zink.

Typology:
Kilian (1975): Phrygian (?)

M 1843.2

Macroscopic characterisation

Description	fibula (foot)
pXRF no.	VO050B
metal	unalloyed copper
L (max)	5.20 cm
Th. (min)	0.20 cm
Th. (max)	0.40 cm
Corrosion	A

Part from fibula foot with round cross-section.

M 1877

Macroscopic characterisation

Description	fibula
pXRF no.	VO012
metal	bronze
Weight (gr)	15.29 gr
L (max)	4.90 cm
D	2.00 cm
Th. (min)	0.20 cm
Th. (max)	0.60 cm
Corrosion	A

Spectacle fibula with three preserved spirals forming a floral pattern.

Typology:
Kilian (1975): Type C
Blinkenberg (1926): Type XIV

M 1909

Macroscopic characterisation

Description	fibula
pXRF no.	VO073
metal	bronze
Weight (gr)	49.58 gr
L (max)	10.85 cm
H (max)	4.65 cm
bow:	
Th. (min)	0.50 cm
Th. (max)	1.85 cm
Corrosion	A

Complete Thessalian bow fibula with decoration of globules and disks on the bow and with catch-plate with upright projection.

Typology:
Kilian (1975): Type D Ip
Blinkenberg (1926): Type VI

M 1928

Macroscopic characterisation

Description	fibula
pXRF no.	VO084
metal	bronze
Weight (gr)	32.65 gr
L (max)	4.40 cm
H (max)	4.90 cm
Width	1.30 cm
Th. (min)	0.10 cm
Th. (max)	0.50 cm
Corrosion	C

Helladic plate fibula with ovoid globule on the bow and large, square catch-plate with incised decoration.

Typology:
Kilian (1975): Type E I
Blinkenberg (1926): Type VII

M 2096

Macroscopic characterisation

Description	fibula
pXRF no.	VO078
metal	bronze
Weight (gr)	58.39 gr
L (max)	10.00 cm
H (max)	1.90 cm
D (single spiral)	4.15 cm
Th.	0.35 cm
Corrosion	B

Spectacle fibula with double spiral of diamond-shaped cross-section.

Typology:
Kilian (1975): Type BII
Blinkenberg (1926): Type XIV

M 2097

Macroscopic characterisation

Description	fibula
pXRF no.	VO047
metal	bronze
Weight (gr)	12.24 gr
L (max)	7.80 cm
H (max)	3.60 cm
Th. (min)	0.15 cm
Th. (max)	0.60 cm
Corrosion	B

Thessalian fibula with simple, round-cross section bow, thicker at the top, and with no coil at the arm-foot joint.

Typology:
Kilian (1975): Type C IIb
Blinkenberg (1926): Type VI

M 2099

Macroscopic characterisation

Description	fibula
pXRF no.	VO049
metal	bronze
Weight (gr)	13.94 gr
L (max)	7.00 cm
H (max)	4.90 cm
Th. (min)	0.30 cm
Th. (max)	0.50 cm
Corrosion	C

Simple bow Thessalian fibula with round cross-section bow, with spring at the arm/foot joint and small catch-plate.

Typology:
Kilian (1975): Type B IIIa
Blinkenberg (1926): Type VI

M 2104

Macroscopic characterisation

Description	fibula
pXRF no.	VO039
metal	bronze
Weight (gr)	4.59 gr
L (max)	5.75 cm
H (max)	2.30 cm
Th. (min)	0.25 cm
Th. (max)	0.35 cm
Corrosion	B

Epirotic fibula of small dimensions.

Typology:
Kilian (1975): Type K IIa
Blinkenberg (1926): Type V

M 2105

Macroscopic characterisation

Description	fibula
pXRF no.	VO087
metal	unalloyed copper
Weight (gr)	2.44 gr
L (max)	4.80 cm
H (max)	2.20 cm
Width	0.20 cm
Th.	0.20 cm
Corrosion	A

Simple, round cross-section bow Thessalian fibula with thin catch-plate.

Typology:
Kilian (1975): Type A IIa

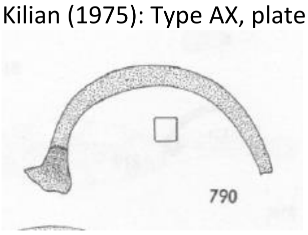
M 2106

Macroscopic characterisation

Description	fibula
pXRF no.	VO017
metal	bronze
Weight (gr)	7.76 gr
L (max)	6.20 cm
H (max)	2.70 cm
Width	0.42 cm
Th. (min)	0.30 cm
Th. (max)	0.40 cm
Corrosion	C

Thessalian, square cross-section bow fibula.

Typology:
Kilian (1975): Type AX, plate 29, no. 790



M 2109

Macroscopic characterisation

Description	fibula
pXRF no.	VO023
metal	bronze
Weight (gr)	8.13 gr
L (max)	6.50 cm
H (max)	2.70 cm
Width	0.45 cm
Th. (min)	0.10 cm
Th. (max)	0.48 cm
Corrosion	B

Thessalian, round, coiled cross-section bow fibula.

Typology:
Kilian (1975): Type A IIIa.b

M 2111

Macroscopic characterisation

Description	fibula
pXRF no.	VO040
metal	bronze
Weight (gr)	6.87 gr
L (max)	5.00 cm
H (max)	2.40 cm
Width	0.70 cm
Th. (min)	0.20 cm
Th. (max)	0.50 cm
Corrosion	C

Epirotic fibula with side projections on the bow and upright projection on the catch-plate.

Typology:
Kilian (1975): Type K IIa
Blinkenberg (1926): Type V

M 2114

Macroscopic characterisation

Description	fibula
pXRF no.	VO076
metal	leaded bronze
Weight (gr)	13.97 gr
L (max)	5.60 cm
H (max)	3.90 cm
Width	1.70 cm
Th. (min)	0.30 cm
Th. (max)	0.60 cm
Corrosion	B

Epirotic fibula with side projections on the bow.

Typology:
Kilian (1975): Type K Ib
Blinkenberg (1926): Type V

M 2116

Macroscopic characterisation

Description	fibula
pXRF no.	VO019
metal	bronze
Weight (gr)	18.56 gr
L (max)	4.30 cm
H (max)	2.90 cm
Width	0.90 cm
Th. (min)	0.30 cm
Th. (max)	1.10 cm
Corrosion	B

Thessalian bow fibula with alternate round globule and disk decoration on the bow.

Typology:
Kilian (1975): Type CIIIk
Blinkenberg (1926): Type VI

M 2117.1

Macroscopic characterisation

Description	fibula
Weight (gr)	5.20 gr
foot:	
pXRF no.	VO051B
metal	unalloyed copper
L	6.60 cm
Th.	0.20 cm
Corrosion	B

M 2117.1: Fibula foot with coil preserved.

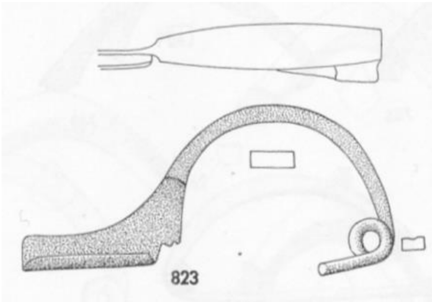
M 2122

Macroscopic characterisation

Description	fibula
pXRF no.	VO21A
metal	bronze
Weight (gr)	9.74 gr
bow:	
L (max)	5.30 cm
H (max)	3.30 cm
Width	0.70 cm
Th.	0.30 cm
foot:	
pXRF no.	VO21B
metal	zinc-rich leaded bronze
L (max)	6.50 cm
Th. (min)	0.20 cm
Th. (max)	0.25 cm
Corrosion	B

M 2122.1: Thessalian bow fibula with rectangular cross-seciton.

Typology:
Kilian (1975): Type FII, plate 30, no. 823



M 2122.2: round cross-section fibula foot.

M 2125

Macroscopic characterisation

Description	fibula
pXRF no.	VO020
metal	unalloyed copper
Weight (gr)	14.93 gr
L (max)	8.20 cm
H (max)	3.50 cm
Width	1.50 cm
Th. (min)	0.40 cm
Th. (max)	0.65 cm
Corrosion	C

Epirotic fibula with side projections on the bow and elongated catch-plate, though the latter is not preserved completely.

Typology:
Kilian (1975): Type K Ib or IIb
Blinkenberg (1926): Type V

M 2136

Macroscopic characterisation

Description	fibula
pXRF no.	VO079
metal	bronze
Weight (gr)	9.07 gr
L (max)	6.75 cm
H (max)	3.90 cm
Width	0.65 cm
Th. (min)	0.11 cm
Th. (max)	0.55 cm
Corrosion	B

Helladic bow fibula with a round swelling on the bow and large, square catch-plate.

Typology:
Kilian (1975): Type D I
Blinkenberg (1926): Type VII

M 2222

Macroscopic characterisation

Description	fibula

pXRF no.	VO014
metal	bronze
Weight (gr)	76.26 gr
L (max)	10.85 cm
D (single spiral)	4.75 cm
Th. (min)	0.30 cm
Th. (max)	0.35 cm
Corrosion	B

Spectacle fibula with double spiral formed of round cross-section wire.

Typology:
Kilian (1975): Type B II
Blinkenberg (1926): Type XIV

M 2226

Macroscopic characterisation

Description	fibula
pXRF no.	VO072
metal	bronze
Weight (gr)	5.22 gr
L (max)	6.70 cm
H (max)	2.30 cm
Width	0.60 cm
Th. (min)	0.15 cm
Th. (max)	0.35 cm
Corrosion	A

Epirotic fibula with side projections on the bow and elongated catch-plate.

Typology:
Kilian (1975): Type K Ia
Blinkenberg (1926): Type V

M 2228

Macroscopic characterisation

Description	fibula
pXRF no.	VO018
metal	bronze
Weight (gr)	12.57 gr
L (max)	5.60 cm
H (max)	3.20 cm
Width	1.00 cm
Th. (min)	0.20 cm
Th. (max)	0.70 cm
Corrosion	B

Complete Thessalian bow fibula. The bow which forms a rather triangular shape is of diamond-shaped cross-section and has a decorative projection at the top. The catch-plate is rather square.

Typology:
Kilian (1975): Type C XI
Blinkenberg (1926): Type VI

M 2229

Macroscopic characterisation

Description	fibula
pXRF no.	VO064
metal	bronze
Weight (gr)	12.67 gr
L (max)	5.20 cm
H (max)	3.25 cm
Width	1.20 cm
Th. (min)	0.20 cm
Th. (max)	0.60 cm
Corrosion	B

Epirotic fibula with side projections on the bow.

Typology:
Kilian (1975): Type K Ib
Blinkenberg (1926): Type V

M 2230

Macroscopic characterisation

Description	fibula

pXRF no.	VO062		
metal	bronze		
Weight (gr)	7.28 gr	Epirotic fibula with side projections on the bow and elongated catch-plate.	
L (max)	7.60 cm		
H (max)	2.60 cm	Typology:	
Width	1.30 cm	Kilian (1975): Type K Ib	
Th. (min)	0.20 cm	Blinkenberg (1926): Type V	
Th. (max)	0.40 cm		
Corrosion	A		

M 2232.2

Macroscopic characterisation

Description	fibula		
pXRF no.	VO115A		
metal	bronze		
Weight (gr)	3.20 gr	Epirotic bow fibula with simple bow.	
L (max)	5.60 cm		
H (max)	2.30 cm	Typology:	
Width	0.50 cm	Kilian (1975): Type K Ia	
Th. (min)	0.20 cm	Blinkenberg (1926): Type V	
Th. (max)	0.30 cm		
Corrosion	B		

M 2234

Macroscopic characterisation

Description	fibula		
pXRF no.	VO065		
metal	leaded bronze	A pair of miniature Epirotic simple bow fibulae and elongated catch-plate.	
Weight (gr)	6.55 gr		
single fibula:			
L (max)	4.60 cm	Typology:	
H (max)	2.10 cm	Kilian (1975): Type K Ia	
Width	0.45 cm	Blinkenberg (1926): Type V	
Th. (min)	0.10 cm		
Th. (max)	0.40 cm		
Corrosion	B		

M 2237

Macroscopic characterisation

Description	fibula		
pXRF no.	VO080	Complete Thessalian bow fibula with large globule with projection at the bow and square catch-plate with upright projection.	
metal	bronze		
Weight (gr)	113.61 gr		
L (max)	11.70 cm		
H (max)	6.80 cm		
Width	2.85 cm	Typology:	
Th. (min)	0.10 cm	Kilian (1975): Type D IIq	
Th. (max)	2.80 cm	Blinkenberg (1926): Type VI	
Corrosion	C		

M 2262

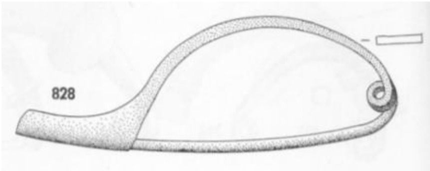
Macroscopic characterisation

Description	fibula

pXRF no.	VO066
metal	leaded bronze
Weight (gr)	12.05 gr
L (max)	9.20 cm
H (max)	3.30 cm
Width	0.90 cm
Th. (min)	0.10 cm
Th. (max)	0.30 cm
Corrosion	C

Thessalian bow fibula with square cross-section bow and rather elongated catch-plate.

Typology:
Kilian (1975): Type FII, plate 30, no. 828



M 2279

Macroscopic characterisation

Description	bird pendant
pXRF no.	VO053
metal	bronze
Weight (gr)	6.38 gr
L (max)	2.40 cm
H (max)	1.60 cm
Width	1.00 cm
Th.	0.40 cm
Corrosion	B

Ring pendant severely fragmented.

Typology:
Kilian (1975): plate 84, no. 29

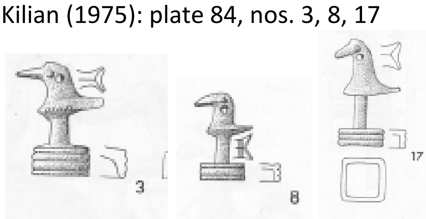
M 2284

Macroscopic characterisation

Description	bird pendant
pXRF no.	VO058
metal	bronze
Weight (gr)	11.31 gr
L (max)	3.90 cm
H (max)	2.90 cm
Width	0.80 cm
Th.	0.50 cm
Corrosion	B

Bird pendant severely corroded, with suspension hole at the head.

Typology:
Kilian (1975): plate 84, nos. 3, 8, 17



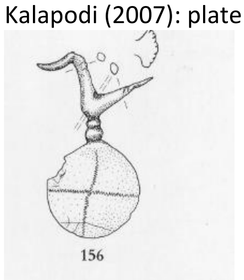
M 2285

Macroscopic characterisation

Description	bird pendant
pXRF no.	VO054
metal	leaded bronze
Weight (gr)	4.53 gr
L (max)	3.00 cm
H (max)	2.20 cm
Width	1.00 cm
Th.	0.20 cm
Corrosion	B

Bird pendant with thin, elongated beak, body and tail. Examples, found at Athena Alea at Tegea (Voyatzis, 1990, 150), while Both Kilian-Dirlmeier and Bouzek classify this bird as a Corinthian type. Kilian-Dirlmeier observes that these birds on pyramidal bases are found all over the Greek mainland, spreading from the Peloponnese to Thessaly, and also outside Greece in the Locrian colony of Locri Epizephyrioi. This last offers a terminus post quem for the type of c. 673 B.C., when the Greek colony was established, while Rolley dates B45 to the second half of the eighth century (Voyatzis, 1990, 286-287)

Typology:
Voyatzis (1990): plate 86, no. B45
Kalapodi (2007): plate 20, no. 156



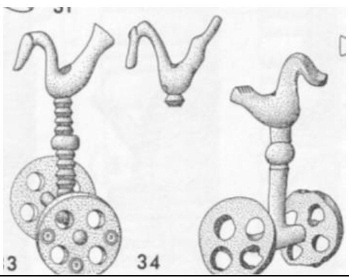
M 2286

Macroscopic characterisation

Description	bird pendant
pXRF no.	VO055
metal	bronze
Weight (gr)	6.92 gr
L (max)	2.70 cm
H (max)	3.00 cm
Width	1.00 cm
Th.	0.20 cm
Corrosion	B

Corinthian type bird pendant dated to the 8th and 7th centuries BC

Typology:
See also M 2285
Kilian (1975): plate 84, nos. 33, 34



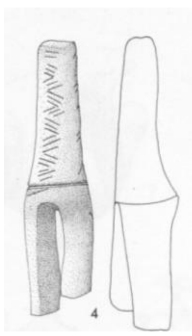
M 2292

Macroscopic characterisation

Description	undiagnosed
pXRF no.	VO048
metal	leaded bronze
Weight (gr)	26.01 gr
H (max)	5.30 cm
Th. (min)	0.50 cm
Th. (max)	1.10 cm
Corrosion	A

Possibly figurine fragment.

Typology:
Kilian (1975): plate 88, no. 4



M 2293

Macroscopic characterisation

Description	bird pendant
pXRF no.	VO125
metal	bronze
Weight (gr)	61.01 gr
L (max)	5.70 cm
H (max)	5.00 cm
Th. (min)	0.40 cm
Th. (max)	2.60 cm
Corrosion	C

Hen pendant, dated to around 700 BC (Voyatzis, 1990).

Typology:
See also M 926.1 and M 926.2

M 3224.1

Macroscopic characterisation

Description	arm band
pXRF no.	VO138
metal	bronze
Weight (gr)	10.94 gr
D	4.75 cm
Width	0.75 cm
Th.	0.35 cm
Corrosion	C

Arm band/armlet with open ends and ovoid cross-section.

Typology:
See also M 1801.1 and M 1801.2

M 3224.2

Macroscopic characterisation

Description	arm band
pXRF no.	VO136
metal	bronze
Weight (gr)	12.53 gr
D	5.00 cm
Width	0.60 m
Th.	0.30 cm
Corrosion	C

Arm band/armlet with open ends and ovoid cross-section.

Typology:
See also M 1801.1 and M 1801.2

M 3224.3

Macroscopic characterisation

Description	arm band
pXRF no.	VO139
metal	bronze
Weight (gr)	11.14 gr
D	5.50 cm
Width	0.60 cm
Th.	0.30 cm
Corrosion	D

Arm band/armlet with open ends and ovoid cross-section.

Typology:
See also M 1801.1 and M 1801.2

M 3224.4

Macroscopic characterisation

Description	arm band
pXRF no.	VO137
metal	bronze
Weight (gr)	21.92 gr
D	6.15 cm
Width	0.65 cm
Th.	0.40 cm
Corrosion	C

Arm band/armlet with open ends and ovoid/diamond-shaped cross-section.

Typology:
See also M 1801.1 and M 1801.2

M 3224.5

Macroscopic characterisation

Description	arm band
pXRF no.	VO140
metal	bronze
Weight (gr)	11.76 gr
D	6.00 cm
Width	0.60 cm
Th.	0.30 cm
Corrosion	C

Arm band/armlet with open, decorated ends and plano-convex cross-section.

M 3229.1

Macroscopic characterisation

Description	arm band
pXRF no.	VO149
metal	bronze
Weight (gr)	22.37 gr
D	6.00 cm
Width	0.60 cm
Th.	0.40 cm
Corrosion	C

Arm band/armlet with overlapping, open ends and rhomboid cross-section.

Typology:
See also M 1801.1 and M 1801.2

M 3229.2

Macroscopic characterisation

Description	arm band
pXRF no.	VO148
metal	bronze
Weight (gr)	15.68 gr
D	6.40 cm
Width	0.60 cm
Th.	0.30 cm
Corrosion	C

Arm band/armlet with open, decorated ends and plano-convex cross-section.

M 3229.3

Macroscopic characterisation

Description	arm band
pXRF no.	VO147
metal	bronze
Weight (gr)	27.29 gr
D	6.50 cm
Width	0.65 cm
Th.	0.40 cm
Corrosion	C

Arm band/armlet with overlapping, open ends and diamond-shaped cross-section.

Typology:
See also M 1801.1 and M 1801.2

M 3229.4

Macroscopic characterisation

Description	arm band
pXRF no.	VO150
metal	bronze
Weight (gr)	15.30 gr
D	7.25 cm
Width	0.60 cm
Th.	0.25 cm
Corrosion	C

Arm band/armlet with open ends and ovoid cross-section.

M 3268

Macroscopic characterisation

Description	fibula
pXRF no.	VO030
metal	bronze
Weight (gr)	15.01 gr
L (max)	7.20 cm
H (max)	3.30 cm
Th. (min)	0.15 cm
Th. (max)	0.55 cm
Corrosion	C

Thessalian simple, round cross-section bow fibula. Severely corroded

Typology:
Kilian (1975): Type B IIIa
Blinkenberg (1926): Type VI

M 3298.1

Macroscopic characterisation

Description	fibula
pXRF no.	VO024
metal	bronze
Weight (gr)	18.32 gr
L (max)	3.00 cm
H (max)	4.30 cm
D (globule)	1.50 cm
Th. (min)	0.50 cm
Th. (max)	0.60 cm
Corrosion	B

Helladic fibula. Only the bow with the round globule decoration is preserved.

Typology:
Kilian (1975): Type E II
Blinkenberg (1926): Type VII

M 3298.2

Macroscopic characterisation

Description	fibula
pXRF no.	VO025
metal	bronze
Weight (gr)	17.02 gr
L (max)	4.20 cm
H (max)	3.80 cm
D (globule)	0.90 cm
Th. (min)	0.40 cm
Th. (max)	0.65 cm
Corrosion	B

Helladic fibula. Only the bow with the round globule decoration is preserved.

Typology:
Kilian (1975): Type E II
Blinkenberg (1926): Type VII

M 3362

Macroscopic characterisation

Description	fibula
pXRF no.	VO086
metal	bronze
Weight (gr)	2.73 gr
L (max)	4.55 cm
H (max)	2.05 cm
Width	0.50 cm
Th. (min)	0.10 cm
Th. (max)	0.30 cm
Corrosion	C

Miniature Epirotic fibula with simple bow and elongated catch-plate.

Typology:
Kilian (1975): Type K Ia
Blinkenberg (1926): Type V

M 4418.2.2

Macroscopic characterisation

Description	metal band
pXRF no.	VO154
metal	bronze
Weight (gr)	10.40 gr
L (max)	8.30 cm
Width	1.20 cm
Th.	0.10 cm
Corrosion	B

Metal band with incised decoration on its one side.

M 4418.2.3

Macroscopic characterisation

Description	fibula
pXRF no.	VO156
metal	bronze
Weight (gr)	4.07 gr
L (max)	5.00 cm
Width	1.55 cm
Th.	0.10 cm
Corrosion	B

Metal band with no decoration.

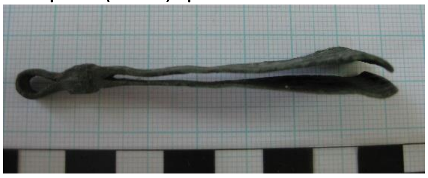
M 4418.5.1

Macroscopic characterisation

Description	tweezers
pXRF no.	VO158
metal	bronze
Weight (gr)	10.38 gr
L (max)	7.20 cm
H (max)	1.10 cm
Width	2.50 cm
Th. (min)	0.10 cm
Th. (max)	0.20 cm
Corrosion	B

Tweezers with incised decoration.

Typology:
Kalapodi (2007): plate 49



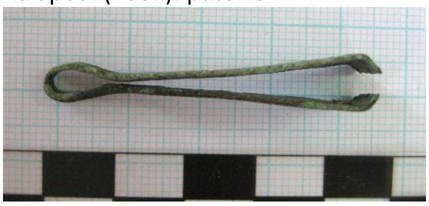
M 4418.5.2

Macroscopic characterisation

Description	tweezers
pXRF no.	VO155
metal	bronze
Weight (gr)	3.61 gr
L (max)	4.40 cm
H (max)	0.70 cm
Width	1.55 cm
Th. (min)	0.10 cm
Th. (max)	0.15 cm
Corrosion	A

Tweezers with incised decoration.

Typology:
Kalapodi (2007): pate 49



M 4418.7.13

Macroscopic characterisation

Description	vessel handle
pXRF no.	VO159
metal	bronze
Weight (gr)	3.18 gr
L (max)	4.55 cm
H (max)	3.80 cm
Th. (min)	0.15 cm
Th. (max)	0.35 cm
Corrosion	A

Handle from vessel of large dimensions.

Typology:
Isthmia (1998): plate 62, nos. 396 (IM 1147), 397 (IM 631)

M 4418.7.16

Macroscopic characterisation

Description	arm band
pXRF no.	VO157
metal	bronze
Weight (gr)	19.69 gr
L (max)	8.60 cm
H (max)	3.20 cm
D (globule)	1.10 cm
Th. (min)	0.10 cm
Th. (max)	0.50 cm
Corrosion	B

Arm band/armlet of thin metal sheet and with decoration on its end.

M 8084/2055

Macroscopic characterisation

Description	fibula
pXRF no.	VO074
metal	bronze
Weight (gr)	34.95 gr
L (max)	9.50 cm
H (max)	4.20 cm
Width	0.95 cm
Th. bow (min)	0.50 cm
Th. bow (max)	0.90 cm
Corrosion	C

Thessalian simple, round cross-section bow with square catch-plate.

Typology:
Kilian (1975): Type B IIIa
Blinkenberg (1926): Type VI

Appendix IV. Metallographic summary

Below follows a metallographic summary for the 70 cut samples examined under the reflected microscope. Aspects of the objects microstructure included below include the metal grain or dendrite structure, the presence or not of slip planes, strain lines, and annealing twins that would indicate stressed grains, the presence and characteristics of any sulphide inclusions and lead prills, the nature of corrosion products, i.e. inter- or intra-granular corrosion, surface patina, growth corrosion layers, preservation state.

sample			microstructure					corrosion			
inv.no.	descr.	section[1]	metal	strain lines	annealing twins	metal-working[2]	S[3]	inter-granular	intra-granular	destru-ctive	growth layers[4]
1308	sheet	X	grains, elongated inclusions	☐	☐	B/C	☒	☒	☐	☐	☐
1309	sheet	X	small grains	☒	☒	D	☒	☒	☒	☐	☒
1310	ring	X	dendrites	☒	☐	A	☒	☒	☐	☐	☐
3673	pin	X	small grains	☒	☒	D	☒	☒	☒	☒	☐
AE 14	ring	X	corroded small grains	☐	☐	-	☒	☐	☐	☒	☒
AE 34	ring	X	grains	☒	☐	C	☒	☒	☒	☐	☐
AE 37	ring	X	grains	☐	☐	B	☒	☒	☐	☐	☐
AE 48	ring	X	corroded small grains	☐	☐	-	☒	☐	☐	☒	☒
AE 66	sheet	X	small grains	☒	☐	C	☒	☒	☒	☐	☐
AE 97	ring	X	grains	☒	☒	D	☒	☒	☒	☐	☐
AE 98	ring	X	small grains	☒	☐	C	☒	☒	☐	☐	☐
AE 103	ring	X	small grains	☐	☐	C	☒	☒	☐	☐	☒
AE 107	spiral	X	grains	☒	☐	C	☒	☒	☒	☒	☒
AE 113	ring	T	small grains	☒	☐	B/C	☒	☒	☐	☒	☐
AE 246	ring	T	small grains	☐	☐	C	☒	☒	☐	☒	☐
AE 249	sheet	X	small grains	☐	☐	C	☒	☒	☐	☒	☒
AE 289	sheet	X	small angular grains	☐	☐	B	☒	☒	☐	☒	☐
AE 459	ring	X	small angular grains	☒	☐	C	☒	☒	☐	☐	☐
AE 480	sheet	X	large grains	☐	☐	C	☒	☒	☐	☐	☐

1 X= cross-section, T= tangential section
2 Scale A to D indicates metalworking intensity from *A* for A structures with no traces of further working to *D* for laborious hammering and hot-working as suggested by the presence of annealing twins
3 Sulphide inclusions (Y/N)
4 Growth corrosion layers do not refer to the thin patina present on the vast majority of ancient bronzes, but rather to thick layers on the objects' surface

sample			microstructure					corrosion			
inv.no.	descr.	section[1]	metal	strain lines	annealing twins	metal-working[2]	S[3]	inter-granular	intra-granular	destru-ctive	growth layers[4]
AE 506	ring	X	thin dendrites	☒	☐	B	☒	☒	☐	☐	☐
AE 507	ring	X	dendrites	☐	☐	A	☒	☒	☐	☐	☐
AE 514	disk	X	grains	☒	☐	C	☒	☒	☒	☐	☒
AE 549	sheet	X	corroded	☐	☐	C	☒	☐	☐	☒	☒
AE 564	ring	X	α-grains	☐	☐	B	☒	☒	☐	☐	☐
AE 578	sheet	X	small angular grains	☐	☐	C	☒	☒	☐	☐	☒
AE 597	ring	X	grains	☒	☒	C	☒	☒	☒	☐	☐
AE 606	sheet	X	dendrites, α-grains	☐	☐	B	☒	☒	☐	☐	☐
AE 619	sheet	X	small grains	☒	☒	D	☒	☒	☒	☐	☐
AE 624	spiral	X	grains	☒	☐	D	☒	☒	☐	☐	☐
AE 633.1	ring	X	large grains	☐	☐	C	☒	☒	☐	☐	☒
AE 651	spiral	X	small grains	☒	☐	C	☒	☒	☐	☒	☒
AE 654	ring	X	corroded dendrites	☐	☐	A	☒	☒	☐	☒	☒
AE 666	nail	X	small grains	☐	☐	C	☒	☒	☐	☒	☒
AE 733.1	ring	T	small grains, dendrites	☐	☐	B	☒	☒	☐	☐	☐
AE 739	spiral	T/X	small grains	☒	☐	B/C	☒	☒	☒	☐	☒
AE 743	ring	X	corroded grains	☒	☒	D	☒	☒	☐	☒	☒
AE 744	sheet	X	small grains	☒	☒	D	☒	☒	☒	☐	☐
AE 752	disk	X	corroded, small grains	☐	☐	C	☐	☒	☐	☒	☒
AE 754	sheet	T	large grains	☒	☒	C	☒	☒	☒	☐	☐
AE 760.1	ring	X	small grains	☐	☐	B/C	☒	☒	☐	☐	☐
AE 760.2	ring	X	grains	☒	☒	C	☒	☒	☒	☒	☐
AE 784.1	ring	X	α-grains	☒	☐	B	☒	☒	☒	☐	☐
AE 796	ring	X	α-grains	☐	☐	B	☒	☒	☒	☒	☒
AE 799	ring	X	corroded grains	☒	☐	C	☒	☒	☐	☒	☒
AE 810	ring	X	grains	☐	☐	B	☒	☒	☐	☐	☐
AE 827	ring	X	angular grains	☐	☐	C/D	☒	☒	☐	☒	☐
AE 838	ring	X	small grains	☒	☐	C	☒	☒	☐	☐	☒
AE 856	ring	X	corroded grains	☒	☐	D	☒	☒	☒	☒	☒
AE 899	spiral	X	small grains	☒	☒	D	☒	☒	☒	☐	☐
AE 929	ring	X	small grains	☐	☐	B	☒	☒	☐	☐	☐
M 495.2	sheet	X	small grains	☒	☐	B/C	☒	☒	☒	☐	☐
M 798	sheet	X	dendrites	☐	☐	B	☒	☒	☐	☐	☐
M 801	sheet	X	corroded grains	☐	☐	-	☒	☐	☐	☒	☐

sample			microstructure					corrosion			
inv.no.	descr.	section[1]	metal	strain lines	annealing twins	metal-working[2]	S[3]	inter-granular	intra-granular	destru-ctive	growth layers[4]
M 1217	sheet	X & T	grains	☒	☐	D	☒	☒	☒	☐	☐
M 1217.1	sheet	X	grains	☒	☐	C	☒	☒	☒	☐	☐
M 1217.3	sheet	X (2)	grains	☒	☒	C	☒	☒	☒	☐	☐
M 1217 C	sheet	X	dendrites, grains	☐	☐	A	☒	☒	☐	☐	☐
M 1314.1	fibula	X	α-grains	☐	☐	B	☒	☒	☐	☐	☐
M 1314.2	fibula	T	small grains	☒	☐	B	☒	☒	☐	☐	☒
M 1652.1	bird pendant	X	corroded	☐	☐	-	☐	☐	☐	☒	☒
M 1683.2	bird pendant	X	corroded dendrites	☐	☐	-	☐	☐	☐	☒	☒
M 1739.1	fibula	X	large grains	☐	☐	C	☒	☒	☐	☐	☒
M 1739.2	fibula	X	grains	☒	☐	D	☒	☒	☒	☐	☒
M 1739.3	fibula	X	grains	☒	☐	C	☒	☒	☐	☐	☒
M 1739.4	fibula	X	grains	☒	☒	D	☒	☒	☒	☐	☒
M 1815.2	fibula	X	corroded grains	☐	☐	C	☒	☐	☐	☒	☒
M 1844	sheet	T	grains	☒	☐	C	☒	☒	☒	☐	☐
M 2117.2	fibula	T	grains	☒	☒	D	☒	☒	☒	☐	☐
M 2233	ring	X	grains	☒	☒	D	☒	☒	☒	☐	☐
M 2265	fibula	T	grains	☐	☐	-	☐	☒	☐	☒	☒
M 2276	pendant	X	dendrites α-grains	☐	☐	A	☒	☒	☐	☒	☒
M 2277	pendant	T	large grains	☒	☒	D	☒	☒	☒	☐	☒
M 3234	other	X	grains	☐	☐	B	☒	☒	☐	☒	☒
M 3367.1	fibula	X	small grains	☒	☒	D	☒	☒	☒	☐	☐
M 3367.2	fibula	T	small grains	☒	☐	B/C	☒	☒	☒	☐	☐
Mu 8100/ 2075	sheet	X	small grains	☒	☒	D	☒	☒	☒	☐	☒

Appendix V. Comparative analysis of object surfaces and metal cores with pXRF and EPMA

Below comparative analytical data are presented for 41 objects a) pXRF analysis on the objects' intact surfaces (XRF2), i.e. including any surface corrosion products and patina layers, b) pXRF analysis of the objects on scraped surfaces after removing any visible corrosion products (XRF1), and c) EPMA analyses the mounted samples' metal core. For analyses averages are presented for the different spot or area analyses as discussed in Chapter 3. This appendix aims to illustrate, on the one hand, the changes that take place on the objects' surfaces during long-term burial, e.g. XRF1 versus XRF2, and, on the other, the analytical differences of sound metal analyses in surface layers with portable XRF equipment and on metal core with more sensitive instruments, e.g. XRF1 versus EPMA. Tables are hereby provided for the nine elements have been analysed with all three protocols, namely copper, tin, arsenic, zinc, iron, lead, manganese, nickel, and antimony.

Table VI.1. Summary table of copper for EPMA, XRF1 and XRF2 methodologies

Sample no.	EPMA	XRF1	XRF2
1310	88.57	89.72	81.91
1309	88.93	85.08	77.93
1308	99.40	98.42	95.88
BE 45741		86.53	71.38
AE 459	87.92	82.80	58.32
AE 480	89.68	84.51	66.99
AE 606	93.82	89.39	78.88
AE 666	90.75	87.37	87.39
AE 810	93.70	87.31	88.33
AE 899	80.48	85.25	82.55
AE 838	89.14	87.77	78.93
AE 929	92.77	81.18	69.31
AE 103	92.43	87.02	83.16
AE 98	92.53	86.83	81.45
AE 827	90.62	87.75	85.32
AE 37	94.04	90.09	85.95
AE 113	93.62	92.71	90.16
AE 97	90.56	90.26	89.53
AE 107	91.05	85.33	78.70
AE 784	84.78	79.61	63.04
AE 624	91.15	87.69	71.36
AE 34	89.27	85.83	70.43
AE 506	79.05	69.22	45.58
AE 564	91.56	87.68	67.70
AE 507	79.46	59.99	45.28
AE 289	99.22	98.78	94.90
AE 760	87.30	88.38	80.67
M 3234	93.59	89.19	70.88
M 3234	93.59	89.19	91.19
M 8100/2	89.70	85.48	87.93
M 1844	92.54	90.09	88.95
M 3367.2	90.78	73.55	69.07
M 3367.1	91.24	88.55	77.58
M 1314.2	89.70	88.37	69.89
M 1314.1	91.21	90.50	86.56
M 495	94.67	92.65	81.97
M 1739.1	87.25	89.31	71.32
M 1739.2	88.82	90.28	76.70
M 1739.3	93.35	92.55	55.96
M 1217 a	91.09	87.18	87.48
M 1217 b	90.99	90.09	85.55
median	91.02	87.75	78.93
mean	90.51	86.82	77.37
max	99.40	98.78	95.88
min	79.05	59.99	45.28

Table VI.2. Summary table of tin for EPMA, XRF1 and XRF2 methodologies

Sample no.	EPMA	XRF1	XRF2
1310	2.46	2.38	3.04
1309	10.33	11.98	14.19
1308	0.01	0.22	0.78
BE 45741		11.55	21.50
AE 459	8.10	11.83	23.36
AE 480	9.91	12.38	20.39
AE 606	5.84	8.07	10.21
AE 666	8.83	10.20	10.88
AE 810	5.78	10.02	9.12
AE 899	17.66	12.52	14.13
AE 838	9.77	10.97	12.81
AE 929	5.41	11.71	18.52
AE 103	6.93	9.04	12.62
AE 98	5.66	9.63	11.34
AE 827	8.82	10.16	12.39
AE 37	5.55	7.38	10.91
AE 113	5.62	5.01	6.77
AE 97	8.63	8.18	6.45
AE 107	7.31	10.85	16.95
AE 784	11.55	13.16	13.37
AE 624	8.07	10.44	22.78
AE 34	4.20	7.04	14.40
AE 506	10.79	11.46	26.54
AE 564	5.96	6.19	13.13
AE 507	10.93	20.55	16.18
AE 289	0.03	0.06	0.04
AE 760	11.55	8.71	14.76
M 3234	5.40	7.59	22.96
M 3234	5.40	7.59	5.46
M 8100/2	9.84	12.86	9.62
M 1844	6.77	7.81	9.35
M 3367.2	8.20	6.55	9.57
M 3367.1	7.88	9.49	14.59
M 1314.2	7.08	6.09	7.44
M 1314.1	6.78	7.24	2.92
M 495	4.47	5.85	11.38
M 1739.1	10.91	8.74	18.64
M 1739.2	10.76	8.57	18.78
M 1739.3	5.91	6.17	37.86
M 1217 a	7.31	10.45	7.07
M 1217 b	7.54	5.86	9.18
median	7.31	8.74	12.62
mean	7.50	8.84	13.23
max	17.66	20.55	37.86
min	0.01	0.06	0.04

Table VI.3. Summary table of lead for EPMA, XRF1 and XRF2 methodologies

Sample no.	EPMA	XRF1	XRF2
1310	8.21	6.52	13.00
1309	0.00	0.00	0.07
1308	0.38	0.14	0.82
BE 45741		0.00	0.00
AE 459	2.44	2.22	10.54
AE 480	0.12	0.33	10.12
AE 606	0.07	0.96	3.88
AE 666	0.00	0.00	0.10
AE 810	0.08	0.05	0.31
AE 899	0.57	0.16	0.90
AE 838	0.00	0.00	0.00
AE 929	0.33	0.00	1.27
AE 103	0.09	0.00	0.98
AE 98	0.99	0.03	2.93
AE 827	0.17	0.00	0.51
AE 37	0.02	0.00	0.13
AE 113	0.04	0.00	0.00
AE 97	0.33	0.00	0.00
AE 107	0.50	0.00	1.46
AE 784	3.00	5.52	21.85
AE 624	0.06	0.04	0.74
AE 34	5.86	5.35	11.29
AE 506	9.49	17.68	25.05
AE 564	1.98	5.02	15.19
AE 507	7.40	15.51	31.62
AE 289	0.24	0.13	0.95
AE 760	0.02	0.07	0.04
M 3234	0.03	0.00	0.28
M 3234	0.03	0.00	0.30
M 8100/2	0.00	0.00	0.11
M 1844	0.01	0.00	0.00
M 3367.2	0.61	0.34	17.72
M 3367.1	0.50	0.30	0.88
M 1314.2	2.79	3.55	17.76
M 1314.1	1.66	1.61	7.44
M 495	0.43	0.50	2.03
M 1739.1	0.89	0.95	3.54
M 1739.2	0.04	0.31	0.56
M 1739.3	0.10	0.00	0.85
M 1217 a	0.00	0.04	1.16
M 1217 b	0.00	0.00	1.40
			13.00
median	0.20	0.05	0.07
mean	1.24	1.64	0.82
max	9.49	17.68	0.00
min	0.00	0.00	10.54

Table VI.4. Summary table of iron for EPMA, XRF1 and XRF2 methodologies

Sample no.	EPMA	XRF1	XRF2
1310	0.02	0.27	0.30
1309	0.13	2.32	7.17
1308	0.00	0.42	1.78
BE 45741		0.84	5.03
AE 459	0.51	1.75	4.86
AE 480	0.01	0.58	1.13
AE 606	0.08	1.00	5.98
AE 666	0.23	0.81	0.60
AE 810	0.18	2.11	1.52
AE 899	0.83	1.33	1.20
AE 838	0.37	0.93	2.41
AE 929	1.13	3.64	8.60
AE 103	0.12	1.01	1.49
AE 98	0.05	1.04	1.92
AE 827	0.02	0.54	0.95
AE 37	0.00	1.22	1.56
AE 113	0.06	1.36	1.55
AE 97	0.02	0.76	2.20
AE 107	0.21	1.58	1.21
AE 784	0.01	0.35	0.57
AE 624	0.15	0.67	3.64
AE 34	0.01	0.60	1.67
AE 506	0.01	0.76	1.19
AE 564	0.01	0.50	2.88
AE 507	0.01	2.41	5.12
AE 289	0.00	0.35	3.31
AE 760	0.03	1.77	3.02
M 3234	0.56	1.73	4.08
M 3234	0.56	1.73	1.85
M 8100/2	0.10	0.50	1.49
M 1844	0.30	1.11	0.75
M 3367.2	0.03	19.08	2.44
M 3367.1	0.01	1.07	5.53
M 1314.2	0.02	1.40	4.34
M 1314.1	0.01	0.28	2.08
M 495	0.23	0.54	2.47
M 1739.1	0.03	0.61	5.51
M 1739.2	0.02	0.41	2.90
M 1739.3	0.19	0.41	3.22
M 1217 a	0.16	1.02	3.27
M 1217 b	0.15	2.68	2.83
median	0.05	1.00	2.41
mean	0.16	1.55	2.82
max	1.13	19.08	8.60
min	0.00	0.27	0.30

Table VI.5. Summary table of arsenic for EPMA, XRF1 and XRF2 methodologies

Sample no.	EPMA	XRF1	XRF2
1310	0.07	0.12	0.33
1309	0.05	0.18	0.12
1308	0.07	0.13	0.00
BE 45741		0.50	1.11
AE 459	0.39	0.55	1.31
AE 480	0.11	0.32	0.41
AE 606	0.07	0.09	0.07
AE 666	0.02	0.09	0.13
AE 810	0.03	0.08	0.21
AE 899	0.17	0.34	0.57
AE 838	0.02	0.00	0.38
AE 929	0.16	0.68	0.93
AE 103	0.17	0.78	0.59
AE 98	0.37	1.30	0.97
AE 827	0.17	0.54	0.17
AE 37	0.15	0.38	0.40
AE 113	0.38	0.27	0.47
AE 97	0.20	0.42	0.43
AE 107	0.46	0.62	0.73
AE 784	0.14	0.35	0.41
AE 624	0.22	0.26	0.34
AE 34	0.03	0.00	0.38
AE 506	0.13	0.37	0.59
AE 564	0.01	0.00	0.11
AE 507	0.05	0.45	0.23
AE 289	0.07	0.14	0.00
AE 760	0.64	0.34	0.39
M 3234	0.14	0.47	0.73
M 3234	0.14	0.47	0.15
M 8100/2	0.14	0.24	0.12
M 1844	0.27	0.39	0.41
M 3367.2	0.17	0.15	0.29
M 3367.1	0.15	0.21	0.30
M 1314.2	0.07	0.14	0.00
M 1314.1	0.06	0.00	0.09
M 495	0.06	0.00	0.42
M 1739.1	0.22	0.00	0.17
M 1739.2	0.07	0.00	0.22
M 1739.3	0.18	0.36	0.95
M 1217 a	0.19	0.13	0.13
M 1217 b	0.22	0.41	0.12
median	0.14	0.27	0.34
mean	0.16	0.30	0.39
max	0.64	1.30	1.31
min	0.01	0.00	0.00

Table VI.6. Summary table of zinc for EPMA, XRF1 and XRF2 methodologies (n.d.= not detected)

Sample no.	EPMA	XRF1	XRF2
1310	n.d.	0.36	0.31
1309	n.d.	0.27	0.34
1308	n.d.	0.31	0.36
BE 45741	n.d.	0.27	0.36
AE 459	n.d.	0.32	0.39
AE 480	n.d.	1.43	0.33
AE 606	n.d.	0.29	0.26
AE 666	n.d.	1.29	0.34
AE 810	n.d.	0.13	0.19
AE 899	n.d.	0.19	0.33
AE 838	n.d.	0.12	4.54
AE 929	n.d.	1.99	0.53
AE 103	n.d.	1.50	0.50
AE 98	n.d.	0.45	0.40
AE 827	n.d.	0.54	0.29
AE 37	n.d.	0.28	0.40
AE 113	n.d.	0.30	0.36
AE 97	n.d.	0.29	0.53
AE 107	n.d.	0.86	0.26
AE 784	n.d.	0.46	0.44
AE 624	n.d.	0.36	0.32
AE 34	n.d.	0.34	0.47
AE 506	n.d.	0.25	0.40
AE 564	n.d.	0.31	0.34
AE 507	n.d.	0.27	0.85
AE 289	n.d.	0.33	0.34
AE 760	n.d.	0.32	0.54
M 3234	n.d.	0.29	0.32
M 3234	n.d.	0.29	0.47
M 8100/2	n.d.	0.59	0.35
M 1844	n.d.	0.35	0.34
M 3367.2	n.d.	0.17	0.27
M 3367.1	n.d.	0.18	0.35
M 1314.2	n.d.	0.22	0.24
M 1314.1	n.d.	0.16	0.29
M 495	n.d.	0.28	1.11
M 1739.1	n.d.	0.28	0.29
M 1739.2	n.d.	0.32	0.33
M 1739.3	n.d.	0.31	0.20
M 1217 a	n.d.	0.34	0.31
M 1217 b	n.d.	0.28	0.46
median	n.d.	0.31	0.34
mean	n.d.	0.44	0.49
max	n.d.	1.99	4.54
min	n.d.	0.12	0.19

Table VI.7. Summary table of manganese for EPMA, XRF1 and XRF2 methodologies (n.d.= not detected, n.a.= not analysed)

Sample no.	EPMA	XRF1	XRF2
1310	n.d.	n.a.	0.11
1309	n.d.	n.a.	0.00
1308	n.d.	n.a.	0.07
BE 45741	n.d.	n.a.	0.09
AE 459	n.d.	n.a.	0.16
AE 480	n.d.	n.a.	0.07
AE 606	n.d.	n.a.	0.19
AE 666	n.d.	n.a.	0.07
AE 810	n.d.	n.a.	0.00
AE 899	0.01	n.a.	0.07
AE 838	n.d.	n.a.	0.15
AE 929	n.d.	n.a.	0.09
AE 103	n.d.	n.a.	0.05
AE 98	n.d.	n.a.	0.13
AE 827	n.d.	n.a.	0.05
AE 37	n.d.	n.a.	0.05
AE 113	n.d.	n.a.	0.14
AE 97	0.01	n.a.	0.17
AE 107	0.01	n.a.	0.03
AE 784	n.d.	n.a.	0.00
AE 624	0.01	n.a.	0.23
AE 34	n.d.	n.a.	0.23
AE 506	n.d.	n.a.	0.14
AE 564	n.d.	n.a.	0.17
AE 507	n.d.	n.a.	0.18
AE 289	n.d.	n.a.	0.06
AE 760	n.d.	n.a.	0.10
M 3234	0.01	n.a.	0.10
M 3234	0.01	n.a.	0.07
M 8100/2	n.d.	n.a.	0.07
M 1844	n.d.	n.a.	0.03
M 3367.2	n.d.	n.a.	0.06
M 3367.1	n.d.	n.a.	0.20
M 1314.2	n.d.	n.a.	0.08
M 1314.1	n.d.	n.a.	0.09
M 495	n.d.	n.a.	0.12
M 1739.1	n.d.	n.a.	0.20
M 1739.2	n.d.	n.a.	0.08
M 1739.3	0.01	n.a.	0.19
M 1217 a	n.d.	n.a.	0.06
M 1217 b	n.d.	n.a.	0.09
median	0.00	-	0.09
mean	0.00	-	0.10
max	0.01	-	0.23
min	0.00	-	0.00

Table VI.8. Summary table of nickel for EPMA, XRF1 and XRF2 methodologies

Sample no.	EPMA	XRF1	XRF2
1310	0.03	0.17	0.22
1309	0.02	0.19	0.19
1308	0.02	0.22	0.24
BE 45741		0.21	0.28
AE 459	0.05	0.19	0.30
AE 480	0.02	0.22	0.28
AE 606	0.03	0.15	0.28
AE 666	0.05	0.23	0.33
AE 810	0.04	0.16	0.25
AE 899	0.06	0.22	0.19
AE 838	0.01	0.13	0.25
AE 929	0.03	0.34	0.25
AE 103	0.03	0.25	0.27
AE 98	0.06	0.40	0.33
AE 827	0.03	0.27	0.19
AE 37	0.16	0.42	0.43
AE 113	0.03	0.20	0.27
AE 97	0.03	0.09	0.28
AE 107	0.04	0.28	0.17
AE 784	0.11	0.34	0.18
AE 624	0.15	0.34	0.36
AE 34	0.40	0.65	0.61
AE 506	0.02	0.12	0.20
AE 564	0.01	0.23	0.21
AE 507	0.04	0.26	0.15
AE 289	0.02	0.14	0.21
AE 760	0.12	0.21	0.24
M 3234	0.04	0.30	0.28
M 3234	0.04	0.30	0.22
M 8100/2	0.02	0.18	0.26
M 1844	0.03	0.19	0.18
M 3367.2	0.06	0.17	0.24
M 3367.1	0.03	0.20	0.32
M 1314.2	0.08	0.23	0.17
M 1314.1	0.07	0.21	0.47
M 495	0.04	0.18	0.29
M 1739.1	0.02	0.12	0.21
M 1739.2	0.02	0.12	0.27
M 1739.3	0.03	0.15	0.15
M 1217 a	0.45	0.30	0.44
M 1217 b	0.45	0.58	0.21
median	0.03	0.21	0.25
mean	0.07	0.24	0.27
max	0.45	0.65	0.61
min	0.01	0.09	0.15

Table VI.9. Summary table of antimony for EPMA, XRF1 and XRF2 methodologies

Sample no.	EPMA	XRF1	XRF2
1310	0.52	0.47	0.79
1309	0.05	0.00	0.00
1308	0.01	0.15	0.08
BE 45741		0.10	0.25
AE 459	0.26	0.33	0.77
AE 480	0.06	0.25	0.29
AE 606	0.00	0.05	0.25
AE 666	0.02	0.00	0.17
AE 810	0.02	0.14	0.08
AE 899	0.15	0.00	0.07
AE 838	0.04	0.09	0.54
AE 929	0.07	0.46	0.49
AE 103	0.09	0.40	0.36
AE 98	0.16	0.33	0.54
AE 827	0.07	0.20	0.14
AE 37	0.03	0.24	0.17
AE 113	0.12	0.17	0.29
AE 97	0.09	0.00	0.42
AE 107	0.28	0.48	0.50
AE 784	0.07	0.21	0.15
AE 624	0.11	0.20	0.24
AE 34	0.00	0.20	0.53
AE 506	0.07	0.15	0.33
AE 564	0.01	0.07	0.28
AE 507	0.20	0.56	0.39
AE 289	0.07	0.07	0.18
AE 760	0.09	0.16	0.24
M 3234	0.16	0.43	0.38
M 3234	0.16	0.43	0.30
M 8100/2	0.05	0.30	0.06
M 1844	0.03	0.06	0.00
M 3367.2	0.09	0.00	0.34
M 3367.1	0.08	0.00	0.26
M 1314.2	0.03	0.00	0.10
M 1314.1	0.03	0.00	0.07
M 495	0.01	0.00	0.21
M 1739.1	0.10	0.00	0.11
M 1739.2	0.09	0.00	0.17
M 1739.3	0.09	0.06	0.62
M 1217 a	0.03	0.54	0.08
M 1217 b	0.02	0.09	0.17
median	0.07	0.15	0.25
mean	0.09	0.18	0.28
max	0.52	0.56	0.79
min	0.00	0.00	0.00